An investigation into the benefits and risks of the integration and application of Reclaimed Asphalt (RA) and Warm Mix Asphalt (WMA) technology into the South African asphalt industry

By

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Declaration

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Abstract

Hot Mix Asphalt (HMA) plays a large role in the transportation infrastructure and is used to construct highways, runways, parking areas, foot paths and cycle paths. Asphalt is thus being produced in massive amounts around the world. The latest figures on asphalt production indicate that 1.6 trillion metric tonnes of asphalt are produced annually worldwide. This vast quantity of asphalt produced annually has a significant effect on the environment, economy and the surrounding society.

According to Mike Acott from the National Asphalt Pavement Association (NAPA) the key strategy to improve HMA is to continuously strive to improve the health safety and environmental practices of HMA. He also emphasises the importance of engaging improvements and innovation in the design and operation phases of HMA as it will result into more health, safety and environmental benefits. (Acott, 2007) It is thus important to improve the sustainability of HMA as it will be used for generations to come.

The purpose of this study is to investigate the potential benefits and risks of applying new technology to the current methods of design and construction of asphalt by the South African asphalt industry. The technologies that are investigated in this study are Warm Mix Asphalt (WMA) technology and the use of Reclaimed Asphalt (RA). WMA is asphalt that is designed to be manufactured at a lower temperature than HMA. RA is the use of recycled asphalt material in Hot Mix Asphalt (HMA) thus replacing virgin aggregate and virgin bitumen with recycled components. Both these technologies can have an effect on the sustainability of HMA.

This study investigates the benefits and risks of the integration and application of WMA technology and RA into HMA industry in South Africa. The study uses interviews along with environmental and cost analyses to investigate this integration.

The findings show that these technologies have definite environmental and cost benefits and that the magnitude of these benefits cannot be ignored. The current use of these technologies is a cause for concern as they are used in limited projects and limited authorities have warmed up to the use of these technologies. The risks involved in using these technologies are caused by a lack of experience and knowledge of these technologies which is aggravated as there are no standard specifications for their use.

It is important that the right strategy is put into place to integrate these technologies into the South African asphalt industry in such a way that minimal risk and monetary losses are achieved.

Opsomming

HMA speel 'n groot rol in vervoer-infrastruktuur en word gebruik om paaie, aanloopbane, parkeerareas, voet en fiets paaie te bou. Asfalt word dus wêreldwyd in groot hoeveelhede geproduseer. Die nuutste syfers toon dat 1.6 triljoen kubieke meter asfalt jaarliks wêreldwyd geproduseer word. Hierdie groot hoeveelheid asfalt wat geproduseer word het 'n beduidende effek op die omgewing, ekonomie en die omliggende gemeenskap.

Volgens Mike Acott van die Nasionale Asfalt Plaveisel Assosiasie (NAPA) is die voortdurende strewe om die gesondheids, veiligheids en omgewings impakte van HMA te verminder die sleutel-strategie om HMA te verbeter. Hy beklemtoon ook die belangrikheid om verbeterings en innovering in die ontwerp en bedryf fases van HMA aan te bring wat kan lei tot meer veiligheids, gesondheids en omgewings voordele. (Acott, 2007) Dit is dus belangrik om die volhoubaarheid van HMA te verbeter as dit bewaar wil word vir toekomstige geslagte te kom.

Die doel van hierdie studie is om die potensiële voordele en risiko's van die gebruik van nuwe tegnologieë op die huidige ontwerp en konstruksie metodes in Suid-Afrika se asfalt bedryf te ondersoek. Die tegnologieë wat in hierdie studie ondersoek word is Warm Mengsel Asfalt (WMA) en die gebruik van Herwonne Asfalt (RA). WMA is asfalt wat ontwerp is om teen 'n laer temperatuur as konvensionele HMA vervaardig te word. RA is die gebruik van herwinde asfalt in HMA wat lei tot die besparing van nuwe aggregaat en bitumen. Beide hierdie tegnologieë kan 'n invloed op die volhoubaarheid van HMA hê.

Hierdie studie ondersoek dus die voordele en risiko's van die integrasie en gebruik van WMA en RA tegnologie in die HMA-industrie in Suid-Afrika. Die studie maak gebruik van onderhoude asook omgewings en koste impak analises om hierdie integrasie te ondersoek.

Die bevindinge in die studie toon aan dat hierdie tegnologie definitief voordelig is vir die omgewing en die ekonomie en dat hierdie voordele groot genoeg is om nie geïgnoreer te word nie. Die huidige gebruik van hierdie tegnologieë is 'n rede vir bekommernis, want dit word slegs in 'n paar projekte aangewend en daar is slegs 'n paar owerhede wat die tegnologieë ondersteun. Die risiko's wat betrokke is in die gebruik van hierdie tegnologieë word veroorsaak deur 'n gebrek aan ondervinding en kennis van die tegnologieë wat verder vererger word deur die gebrek aan standaard spesifikasies vir die gebruik daarvan.

Dit is belangrik dat die regte strategieë in plek gesit word om hierdie tegnologieë te integreer in die Suid-Afrikaanse asfalt bedryf. Dit moet op so 'n manier geintegreer word dat minimale risiko's en finansiële verliese veroorsaak word.

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Glossary of Abbreviations

AA	Automobile Association
AADE	Average Annual Daily E80's
ADE	Annual Daily E80's
BTB	Bituminous Treated Base
CAPA	Colorado Asphalt Pavement Association
CAPSA	Conference on Asphalt Pavement in Southern Africa
COLTO	Committee of Land Transport Officials
CPA	Cape Provincial Administration
CSIR	Council of Scientific and Industrial Research
EAPA	European Asphalt Pavement Association
EU	European Union
GAMA	Group of Africa Member Association
GHG	Green House Gasses
HFO	Heavy Fuel Oil
HMA	Hot Mix Asphalt
ISO	International Organisation for Standardisation
LAMBS	Large Aggregate Mixes for Bases
LBF	Light Burner Fuel
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
MIT	Massachusetts Institute of Technology

MJ	Mega Joule
NAPA	National Asphalt Pavement Association
PWOC	Present Worth of Costs
RA	Reclaimed Asphalt
RE	Resident Engineer
Sabita	Southern African Bitumen Association
Sanral	South African National Roads Agency Ltd.
Sapref	South African Petroleum Refineries (Pty) Ltd
SAT	Society for Asphalt Technology
SMA	Stone Mastic Asphalt
TRB	Transportation Research Board
TRH	Technical Recommendations for Highways
UK	United Kingdom
UTFC	Ultra-Thin Friction Course
VMA	Voids in Mineral Aggregate
WMA	Warm Mix Asphalt
WMAIG	Warm Mix Asphalt Interest Group

CHAPTER 1: INTRODUCTION

Chapter 1 includes a brief background that leads to the formulation of the problem statement of the study. The chapter also includes an outline and a graphical illustration of the study. A chapter overview is provided to summarise the events in each chapter. The methodology that is followed through the study is described as well as the primary and secondary objectives of the study.

1.1 Background

Hot Mix Asphalt (HMA) can be described as a mixture of a specific graded aggregate and an asphalt binder (penetration or modified bitumen) that also contains air voids. The mixture is produced at a temperature of between 150°C and 190°C and then compacted into a layer (with a specific thickness onto the base layers of a pavement structure) (Transportation Research Board (TRB), 2011). The nominal percentage components within the mix are shown below:

- Aggregate: 85% - 95%
- Asphalt binder: 3% - 8%
- Absorbed binder: < 1%
- Air: 2% - 20%

(Transportation Research Board (TRB), 2011)

HMA plays a large role in the transportation infrastructure and is used to construct highways, runways, parking areas, foot paths and cycle paths. Asphalt thus has an effect on the economy of developed and developing countries (Mangum, 2006). According to the National Asphalt Pavement Association (NAPA) Europe invests (public investments) a total of €80 million annually on bridges, highway and street construction. NAPA also states that the United States of America (USA) invests (public investments) $55 million annually on bridges, highways and streets (National Asphalt Pavement Association, 2011). The latest figures on asphalt production indicate that 1.6 trillion metric tonnes of asphalt are produced annually worldwide (National Asphalt Pavement Association, 2011). This indicates that asphalt have a significant impact on the economy and the social well being of the public.

This vast quantity of asphalt produced annually has a significant effect on the environment and the surrounding society. According to Mike Acott from the National Asphalt Pavement Association (NAPA) the key strategy to improve HMA is to continuously strive to improve the health safety and environmental practices of HMA. He also emphasises the importance of engaging improvements and innovation in the design and operation phases of HMA as it will result into more health, safety and environmental benefits. (Acott, 2007) According to the Southern African Bitumen Association (Sabita) there are four aspects of environmental conservation that are influenced by the asphalt industry, they are:

- Reduced reliance on non-renewable resources,
- The release of harmful emissions into the atmosphere,
- Contamination of water resources,
- Noise.

These aspects indicate that HMA is a material that can potentially be made more sustainable. Acott (2007) defines sustainability as follows:

"Sustainability: Meeting the needs of the present without compromising the ability of future generations to meet their own needs."

HMA has three important characteristics of a sustainable construction material, they are:

- HMA has low energy consumption,
- HMA has a long life,
- HMA is recyclable.

According to a study Gambatese & Rajendran (2005) many product, equipment and operation innovations have proven that the energy consumption of HMA can be lowered and improve the sustainability of HMA even more. They also mention two ways to improve sustainability of HMA namely to minimise the energy usage of HMA and to apply materials in such a way to minimise the waste.

The paragraphs above indicate that innovation and improvements of HMA design and construction is a method of improving its impact on the environmental, sustainability and the economy. Innovations and improvements are applying new technology to the current asphalt production systems.

The purpose of this study is to investigate the potential benefits and risks of applying new technology to the current methods of design and construction of asphalt by the South African asphalt industry.

The technologies that are investigated in this study are Warm Mix Asphalt (WMA) technology and the use of Reclaimed Asphalt (RA). WMA technology was first used in South Africa in 2008 when initial trials were conducted to find out if this technology can be used in South Africa. These trials also included RA which is recycled asphalt. These trials stretched from November 2008 to December 2010. The trials were successful and lead to the eThekwini Municipality in Kwazulu Natal including this technology in their HMA arsenal. (Lewis & Naidoo, 2011)

Tony Lewis and Krishna Naidoo (2011) stated that the WMA technology can be successfully used with RA and that the quality of the asphalt is just as good as normal HMA.

Tony Lewis and Krishna Naidoo stated the following in the Sabita AsphaltNews in 2012:

"There is no doubt that the success achieved in the routine use of WMA in the Durban area will soon spread to other areas as the benefits of this process in terms of reduced cost, as well as improvements in environmental and working conditions, become more widely known."

A brief overview of RA and WMA technology is provided below:

Reclaimed Asphalt (RA) Technology:

RA is the use of recycled asphalt material in Hot Mix Asphalt (HMA). The aged asphalt is normally milled out of the existing pavement, then crushed and screened into the different aggregate sizes and stockpiled for immediate use or for future use. The aggregate as well as the binder is reused during this process. The RA is combined with virgin aggregate and binder to produce Reclaimed Asphalt Pavement. RA has been preferred above virgin materials because of the reduction in carbon footprint and the reduction in the use of natural resources. RA has economical, technical and environmental advantages. (Al-Qadi et al., 2007)

RA is the largest recycled product in the world. Each year 90 million tons of RA is reused. This is almost double the combined amount of paper, plastic, glass and aluminium recycled annually. According to the National Asphalt Pavement Association (NAPA) in the United States, RA saves the tax payers up to $300 million annually by reducing material procurement costs as well as material disposal costs. It has also been noted that the HMA manufactured with RA will increase the lifespan of the pavement because the RA has already undergone oxidation (which normally accelerates the aging process). (Colorado Asphalt Pavement Association (CAPA), 2009).

Warm Mix Asphalt (WMA) Technology:

WMA is asphalt that has been designed to be manufactured at a lower temperature than HMA. HMA is normally manufactured between 150°C and 190°C while WMA is manufactured at a temperature of 20°C lower that HMA (Lewis, 2009). This has a significant impact on the sustainability of the production process. The structural quality of WMA is considered to be the same as conventional HMA (Nortje & Lewis, 2011).

Some of the main benefits include a reduction of the emissions from the manufacturing plants, improvement of the working environment, better engineering benefits and a reduction in the use of energy. (Lewis et al., 2011)

1.2 Problem Statement

This study investigated the benefits and risks of the integration and application of Warm Mix Asphalt (WMA) technology and Reclaimed Asphalt (RA) into the Hot Mix Asphalt (HMA) industry in South Africa.

1.3 Scope of Work

The following main boundaries were set for this study:

- The study investigated specifically the South African asphalt industry.
- WMA and RA are the only technologies that were investigated and compared to conventional HMA. Other technologies especially cold in place (or cold in plant) recycling are the main competition of RA and WMA technology in South Africa. These technologies are however not included in the scope of this study as this will make the study to complex and broad.
- The investigation specifically addressed the aspects of production and construction of HMA and the integration of RA and WMA technologies into the South African asphalt industry.

Chapter 2 identified shortcomings in HMA. These shortcomings are limited to the following four aspects:

- quality;
- environmental aspects;
- health and
- costing aspects.

Interviews that were conducted in Chapter 3 are performed with South African practitioners (including clients, consulting engineers, contractors and researchers) that are familiar with these technologies and who can provide insightful information of the state of these technologies in South Africa.

A case study was described in Chapter 4 that is based on a current project in South Africa. The data was thus procured from local sources (contractors, suppliers and engineers) that are working on the specific project. An environmental analysis (Chapter 5) and cost analysis (Chapter 6) were done on the case study. These analyses are thus limited to the design specifications of the specific project. The analyses are based on the ISO 14040 (International Organization for Standardization, 1997) document. The analyses are thus defined (as stated in the ISO 14040 document) in compliance to the guidelines provided in the ISO 14040 document.

1.4 Objectives of the Study

The primary objectives of this study are listed below:

- To motivate the choice of WMA and RA technologies as suitable technologies for economic and other benefits.
- To investigate what elements (health, environmental impact, quality and cost impact) of HMA will be affected by using new asphalt technology (WMA and RA technologies).
- To select an appropriate research approach (case study, environmental and cost analysis) to determine the effect of these technologies, as well as to determine the magnitude of the effect on HMA elements (environment and cost).
- To identify the benefits and risks of these technologies on HMA and the South African asphalt industry.
- To provide South African literature for further studies in this direction.

Secondary objectives of the study are listed below:

- To identify aspects for future research and to provide recommendations for the further integration of these technologies in the South African asphalt industry.

1.5 Graphical Illustration and Methodology of the Study

Figure 1 shows the framework of the study. Each chapter is overviewed below figure 1.

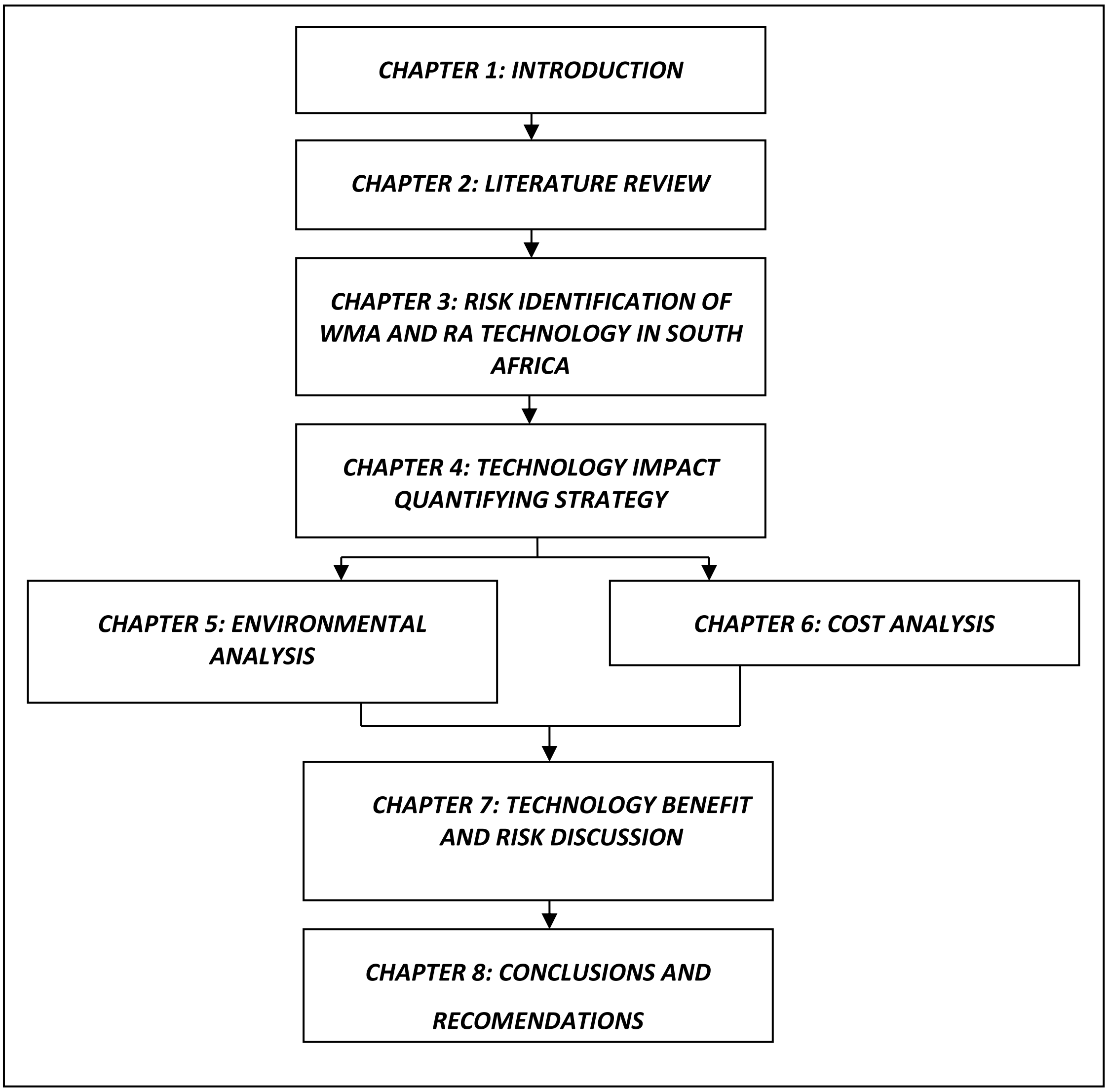

Figure 1: Thesis Framework

The chapter overview on the next page provides a short summary of each chapter in the study.

CHAPTER 1: INTRODUCTION

Chapter 1 provides a short background of the technology that was investigated in this study. The chapter also includes the graphical illustration of the study, methodology, objectives as well as the scope of the study.

CHAPTER 2: LITERATURE REVIEW

Chapter 2 provides a thorough literature review that sets the basis for understanding the asphalt technology that is considered in the study. Hot Mix Asphalt (HMA) is defined shortly. The life cycle of HMA is defined and divided into the different life phases of HMA. The problems of each life phase are identified through literature and a summary of all the shortcomings are listed in a table. The shortcomings are also categorised (environmental, health, cost and quality). The benefits of the RA and WMA technologies are also listed. A benefit-solution investigation was done to find out which of the shortcomings can be benefited by these technologies. This chapter uses three elements to motivate the selection of WMA and RA technology as the preferred technology to investigate in this study. These three elements are:

- HMA problem identification that identifies potential areas or areas that can possibly be improved by the use of new technology. This problem identification specifically focuses on four elements: health, environment, quality and cost. This is compared to the potential benefits of the WMA and RA technology (also obtained from literature). This shows that the selected technology can have a positive effect on the identified problem areas.
- A literature study on the success of these technologies internationally. This shows that the technology can be used successfully and that it can be beneficial to the South African asphalt industry.
- A review of previous research done in the field of analysing the benefits of these technologies.

This narrows the investigation down to the use of WMA and RA technology. It also emphasises that the investigation is aimed at the South African asphalt industry.

The phases of HMA that are affected by these technologies are identified as well as the specific categories (environmental, health, cost and quality). This narrows down the parameters for the rest of the study. The effect of WMA and RA technologies on the quality of the asphalt is investigated through literature and it is found that it does not reduce the quality of the asphalt. The effect of these technologies on the environment and on project cost is identified as the focus point for the remainder of the study. Prior research is looked at to find methods to analyse the categories and phases that were identified. Through the prior research a life cycle analysis (environmental analysis) and a life cycle cost analysis (cost analysis) are identified as the methods to quantify the magnitude of the technologies' benefit.

CHAPTER 3: RISK IDENTIFICATION OF WMA AND RA TECHNOLOGY IN SOUTH AFRICA

Chapter 3 investigates the use of these technologies in South Africa. Interviews with various role-players in the asphalt production and application system served as a basis (source) for establishing the scope of the application of the technologies. This includes asphalt producers and contractors, researchers, consulting engineers and clients. These practitioners were interviewed to get a better understanding about the following:

- Current use of these technologies in South Africa,
- The expected growth of these technologies in South Africa,
- Provincial interest in South Africa,
- Technology risk identification.

The interviews are also used to confirm that the main benefits of the technologies are the reduction in environmental and cost impact. The risks are identified in the design, production and construction phases of these technologies.

CHAPTER 4: TECHNOLOGY IMPACT QUANTIFYING STRATEGY

Chapter 4 describes the strategy that is used to do the environmental and cost analyses. This description includes:

- Quantification methods,
- Case study,
- Scope and limitations of the analyses,
- Quality assurance of the results,
- Mix models definition.

A current project on the N1 is used as a case study to conduct environmental and cost analyses as the project uses both the investigated technologies.

CHAPTER 5: ENVIRONMENTAL ANALYSIS

Chapter 5 investigates the environmental impact of the technologies by implementing a Life Cycle Assessment (LCA) that compares a conventional HMA mix to an HMA mix that uses the WMA and RA technologies. The analysis is quantified in energy consumption (MJ). The LCIA is performed on the case study that is defined in Chapter 4. This chapter thus concludes on the magnitude of the environmental impact of these technologies on a project in South Africa.

CHAPTER 6: COST ANALYSIS

Chapter 6 investigates the cost impact of the technologies by conducting a Life Cycle Cost Analysis (LCCA) on a conventional HMA mix and a HMA mix that uses the new technologies (the LCCA is also done on the same case study as in Chapter 5). The conclusion of this chapter thus provides the magnitude of the impact of the technologies on a South African project.

CHAPTER 7: TECHNOLOGY BENEFIT AND RISK DISCUSION

Chapter 5 and Chapter 6 demonstrate the impact of the technologies on the environmental and cost aspects of the South African asphalt industry. This chapter discusses the benefits these technologies hold for the South African asphalt industry. The chapter also discusses the risks involved in using these technologies. The risks as well as the benefits are listed and evaluated. This chapter puts the risks and benefits into context with each other.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

Chapter 9 provides the final conclusion as well as the recommendations for possible further investigations into these technologies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a literature review that investigates the impact of asphalt technology (Warm Mix Asphalt (WMA) and Reclaimed Asphalt (RA)) on the life span of Hot Mix Asphalt (HMA) in South Africa. A brief background of HMA composition and HMA types are given. The literature review also includes a section that considers prior research done for similar topics.

A benefit-solution investigation is also done. This investigation identifies the shortcomings of HMA and identifies the benefits of the technologies. The benefits are then compared to the identified shortcomings to find out if they can serve as solutions for some of them. The life cycle of HMA is properly defined and the different processes or phases are identified. Five HMA phases are identified, being procurement, production, construction, service life and end-of-life. These phases are individually investigated to identify shortcomings or areas that can be improved where technology can have a potential positive impact. These shortcomings are listed to provide a basis from where to perform a technology investigation to investigate what shortcomings can be addressed by applying RA and WMA technology. This is used to motivate the use of these technologies in this study.

After the shortcomings have been identified and listed, and an appropriate technology has been selected it is possible to identify the specific benefits that this technology can have on HMA in South Africa. The HMA phases that benefit from this technology are also identified.

The end result is to be able to narrow down the study to the most important elements that can be analysed to determine the benefits and possible risks of the technology on HMA in South Africa.

Prior research is also consulted to identify possible methods of analysing the benefits.

The aims of this chapter are to:

- Identify the shortcomings with HMA in its different phases of its life time that can possibly be improved.
- Identify technology that can have a positive impact on these shortcomings.
- Determine the HMA phases that will be influenced by this technology.
- Identify and narrow down the elements that will be analysed in the rest of the study (quality, cost, environmental and health).

- Consult prior research to identify methods to analyse the benefits.

2.2 Hot Mix Asphalt (HMA)

HMA plays a large role in the lives of human beings as well as in the transportation industry. It is used as a construction material to build asphalt highways, secondary roads, parking lots, airport runways, etc.

HMA is a mixture of aggregate, filler and binder. The aggregate is normally crushed rock, sand, gravel or slag. The binder consists of bitumen and modification agents. These components are mixed into a cohesive mixture that is applied to create a driving surface for vehicles. Asphalt has many modifications that allow the mixture to adapt to the weather conditions on site as well as to traffic conditions (European Asphalt Pavement Association, 2010). The aggregate can also be used in certain gradations. Gradations are different sizes of particles that are distributed as percentages of the total weight to form a spectrum of different aggregate sizes in an asphalt mix. These modifications and gradations allow the engineer to design a mixture that can reduce the traffic noise, improve the durability, improve the skid resistance of tyres, reduce spray during rain and ensure a smoother ride for road users. Today modifications are also used for green engineering to reduce the environmental impact as well as to improve the lifespan of an asphalt mixture (National Asphalt Pavement Assotiation (NAPA), 2013).

The three components of HMA, aggregate, binder and filler are discussed below.

2.2.1 HMA Components

A. Aggregate

Mineral aggregates are hard, inert materials (normally crushed rock, sand, gravel or stone dust). These aggregates undergo tests to ensure that the mineralogy and dimensional properties are sufficient to be used in asphalt production. The aggregates are then properly graded and mixed with the binder to produce the asphalt mixture. Aggregate fills between 75% and 85% of the asphalt volume (about 90% to 95% of the weight). (Asphalt Pavement Association of IOWA, 2010)

Aggregate Gradation (Sivan & Matthew, 2009)*:*

Aggregate gradation is the distribution of aggregate in certain proportions of different sizes (as a percentage of the total weight). These proportions are made up of a percentage of the total unit weight of the sample. The gradation of a certain aggregate has a very important influence on the properties of the asphalt mix. These properties include: stiffness, stability, permeability, durability, workability, skid resistance, fatigue resistance and resistance to moisture damage. It is often interpreted that the grading with the highest density is the ideal grading, because of the good stability of a highly dense mix. However, an asphalt mix must provide voids for the bitumen binder to ensure that the mixture has enough adhesion. The mix must also have air voids that allow space for secondary compaction and also to avoid rutting. Asphalt gradation is thus the most important factor when designing an asphalt mix. Standard gradation limits are provided by certain specifications that are used by most engineers. The document most generally used in South Africa is the Standard Specifications of Road and Bridge Works of State Road Authorities provided by the Committee of Land Transport Officials (COLTO) (1998).

B. HMA Binders

HMA binder can be seen as the glue that keeps the asphalt mix together. The binder is described as the residue of oil refining with waterproof and thermoplastic adhesive characteristics. This binder, that is also called bitumen, is produced according to certain grading specifications. These grading specifications give the bitumen certain properties which can also be enhanced by adding modifiers. (Anderson et al., 2010)

The following paragraphs will discuss the properties of bitumen, the classification of bitumen as well as bitumen modifiers.

- *Properties of bitumen* (Read & Whiteoak, 2003)*:*

Viscosity and temperature susceptibility are the two most important properties that need to be understood when working with bitumen. These properties determine the properties of the final asphalt pavement.

Viscosity refers to the way bitumen flows. If bitumen flows easily it has a low viscosity. Viscosity can be seen as the degree in which bitumen shows resistance to flow. The viscosity has an effect on the rate of deformation as well as the permanent deformation.

- *Classification of Bitumen* (Read & Whiteoak, 2003)*:*

The penetration of bitumen is dependent on two basic tests. These tests are the penetration test and the softening point test. Both these tests are discussed in Appendix A.

Following the results of these tests, the bitumen can be specified and identified. Table 1 shows different penetrations and softening points (Read & Whiteoak, 2003). These grades are prescribed by the engineer for a specific project dependent on the conditions of project location (weather, traffic, etc.).

Table 1: Bitumen Grade Designations

	Unit	Test Method (British Standards Institution (BSI), 2000)	20/30	30/45	35/50	40/60	50/70	70/100	100/150	160/220
Penetration at 25°C	**0.1 mm**	**EN 1426**	20-30	30-45	35-50	40-60	50-70	70-100	100-150	160-220
Softening point	**°C**	**EN 1427**	55-63	52-60	50-58	48-56	46-54	43-51	39-47	35-43

Example: The 50/70 pen bitumen means that the penetration was measured between 50 and 70. It can also be seen that the softening point is between 46 and 54 degrees Celsius.

- *Modified Bitumen:*

In general, roads are served well by conventional asphalts. The demand on roads however increases annually. The large amount of heavy vehicles (with larger axle loads) on the roads as well as the increasing use of super single tyres (as opposed to the conventional axles with double tyres) drastically shortens the lifespan of the roads. Therefore road engineers have experimented with bitumen modifiers that can change the properties of the asphalt in such a way that it can lengthen the lifespan of the roads.

Modified bitumen can be classified into two main groups called homogeneous and non-homogeneous binders. Homogeneous binders are modified with an additive so that the material density of the modifier-bitumen mix is homogeneous. The non-homogeneous binders are modified in such a way that there are particles in the modifier-bitumen mix that have different densities. (For example: adding crumbed rubber from tyres). (Rossmann et al., 2007)

The modifiers are further classified as either a plastomer or an elastomer. An elastomer modifies the bitumen to improve its elasticity. This improves the ability of the asphalt to deform under a large load and its ability to return to its original form. A plastomer improves the stiffness and strength of the asphalt but does not improve the recovery of the asphalt. (Rossmann et al., 2007)

Table 2 shows the two groups of modified binders that are most frequently used in South Africa (Rossmann et al., 2007). The modifiers that are listed below each have a spectrum of modifiers that are classified under them as well.

Table 2: Bitumen Modifiers

Homogeneous binders		Non-Homogeneous binders	
Styrene-butadiene-styrene (SBS)	*Elastomeric*	Crumbed rubber	*Elastomeric*
Synthetic styrene-butadiene-rubber (SBR)	*Elastomeric*		
Natural rubber latex	*Elastomeric*		
Ethylene-vinyl-acetate (EVA)	*Plastomeric*		
Styrene Isoprene Rubber (ISIR)	*Elastomeric*		

There is also another modifier that is different from those listed above. It is called a hydrocarbon modifier. These modifiers are used to increase the softening point of the bitumen thus increasing the stiffness. It also reduces the susceptibility of the asphalt to temperature (Rossmann et al., 2007).

Table 3 (Rossmann et al., 2007)shows the commercial naming system used to identify different modified binders. For example: A-P1 means that the binder can be used for asphalt and it is modified with a plastomer (modified less than an A-P2)

Table 3: Identification of Modified Binders

Type of Application		Type of binder		Type of modifier		Modification level
Seal	S	Emulsion	C	Elastomer	E	A higher numerical value indicates a higher level of modification
Asphalt	A	Pen Bitumen	None	Plastomer	P	
Crack sealant	C			Rubber	R	
				Hydrocarbon	H	

C. Filler

Fillers are the fine materials that pass through the 0.075mm sieve size. Sometimes fillers are added to the mix to improve the gradation of the mix. These fillers have the following properties (Sabita, 2005):

- It can be used as void filler, thus changing the gradation properties and volumetric parameters of the mix.
- It acts as an extender for the binder that stiffens up the mix and can lead to better durability.
- It can also improve the bond between the aggregate and the asphalt binder.

The fillers that are generally used in practice are: Hydrated lime (active filler), fly ash, Portland cement (active filler) and baghouse fines. The active fillers must be monitored for their effect on the stiffness because very high stiffness can cause problems with the compatibility of the asphalt. Some of these fillers are very sensitive to changes in the binder content. The production of these filler mixes must thus be very accurate and regularly monitored. Fillers are expensive and must be used with care. (Sabita, 2005)

2.2.2 Types of HMA

There are four main types of HMA that are regularly used in South Africa and they are (Transportation Research Board (TRB), 2011):

- Densely graded mixes
- Stone Mastic Asphalt (SMA)
- Open-graded mixes
- Large Aggregate Mixes for Bases (LAMBS)

These four types of asphalt will be discussed in the following paragraphs. The following discussions are based on the User Guide for the Design of Hot Mix Asphalt by Sabita (Sabita, 2005).

- ***Densely Graded Mixes (Sabita, 2005):***

Densely graded mix design is very common and can be used in low and high traffic capacities. These mixes are also called sand-skeleton mixes. These mixes receive this name because of the well-graded fine aggregate that fills the gaps between the coarse aggregate after compaction. The mix is thus dependent on the fines to provide stability to the mix. Densely graded mixes include: continuously graded, gap-graded and semi-gap-graded mixes. These gradations are shown in Appendix B. Each of these mixes can have different maximum aggregate sizes (9mm, 13.2mm, 19mm, 26mm and 37.5mm). Asphalt that is used for base layers normally has larger maximum aggregate sizes than asphalt used for the surfacing layer. The maximum stone size in these mixes is also determined by looking at the thickness of the required asphalt layer as well as the required properties such as stability and permeability. The binder content of a densely graded mix must be determined by understanding the volumetric characteristics and compaction at different binder contents.

- ***Stone Mastic Asphalt (SMA) (Sabita, 2005):***

SMA is an asphalt design that is best suited for heavy traffic flows. This design relies on its stone structure for stability. SMA has a coarse gap-graded structure (as seen in Appendix B) that is bonded together with mastic. This mastic is made up of filler, asphalt binder and fibres. The selection of the correct mastic composition is important to ensure that the contact between the stones is maintained. The SMA normally uses more binder than the conventional densely graded asphalt. SMA is applied with a thickness of less than 40mm. The thin stone structured asphalt is easier to compact than more dense structures. A well designed SMA has the following properties:

- Excellent resistance to permanent deformation;

- High durability;
- High wet weather skid resistance (better than densely graded mixes);
- Better traffic noise reduction than densely graded mixes.

- ***Open-graded Mixes (Sabita, 2005):***

Open-graded mixes (as seen in Appendix B) are generally used as a thin surface layer (40mm is recommended) on top of an existing asphalt layer. These mixes have up to 20% voids that are interconnected and have a stone structure. Open-graded mixes are not applied for their durability but rather for their good permeability thus better visibility (less spray) and their noise reduction (voids leads sound away). Open-graded mixes have a few considerations that have to be considered during the design phase that include:

- The high permeability requires the next layer to be impervious to keep water away from the bottom layers.
- Open-graded and have a very low stiffness and must thus only be used as surfacing and not as a structural layer.
- The low durability requires the binder content to be as high as possible to maximise adhesion. This however can lead to binder drain-down (binder moving and settling at the bottom of the mix) during construction.

- ***Large Aggregate Mixes for Bases (LAMBS) (Sabita, 2005):***

LAMBS are heavy duty asphalt that are used as a main structural layer that is normally covered by another surfacing layer. These mixes are used for areas with heavy loading over their life span (over 10 million E80's) such as some loading facilities and airports. LAMBS make use of large aggregate sizes such as 37.5mm and 53mm. These mixes don't have a specific gradation. The gradation must provide good interlocking among the aggregates because LAMBS' strength and resistance against permanent deformation are obtained through strong interlocking. Gradations such as open-graded and gap-graded are not suitable (LAMBS are usually continuously graded). No consideration needs to be given to noise reduction and skid resistance as the LAMBS service as a supporting layer and not as a final surface layer. Because of the large aggregate and good interlocking the surface area as well as the voids in the mineral aggregate (VMA) within the mix are reduced and thus require less binder.

2.2.3 Asphalt Production in South Africa

HMA is manufactured in a drum or a batch plant. The components of these plants are properly defined in Appendix C. The following paragraph provides an overview of the current state of asphalt plants in South Africa.

Asphalt production in South Africa is beginning to incorporate more technological advances into the manufacturing methods and processes. Both batch and drum plants are used, however there is a preference for the use of drum over batch plants, mainly due to the cost difference between the two types. South African asphalt manufacturers use both mobile and fixed type plants, with mobile plants being popular because of the ability to disassemble and move to a different project quickly and cost effectively. This is especially useful in South Africa where outlying regions mostly require asphalt on a contract by contract basis, meaning that the mobile plants can be moved in and out as may be required. Permanent (Fixed) plants are normally larger, much more expensive to establish and are situated in regions that are more densely populated and that have road networks that require on-going larger and sustainable volumes of asphalt for new construction as well as maintenance. Asphalt plants in South Africa have also undergone computerisation over the last couple of years; resulting in reduced human error and improved overall quality control. The introduction of the use of Reclaimed Asphalt (RA) has also led to the configuration of the plants components to accommodate this new production technology and RA contents as high as 40 to 50% are now becoming the norm.

The following section motivates the use of WMA and RA technology as an appropriate technology that can improve the HMA industry in South Africa.

2.3 Technology Benefit-Solution Investigation

The following subsections investigate the use of WMA technology and RA as an appropriate technology to apply in South Africa. These paragraphs are also the motivation to further investigate these technologies in this study.

This section includes the identification of shortcomings or potential improvement areas in the HMA life cycle. The benefits of RA and WMA technology are also identified and listed. The benefits of the technology are then weighed up as solutions to these shortcomings to identify the impact it may have on the asphalt industry as well as on what specific areas (health, environmental impact, quality and cost impact) the impact occurs.

Figure 2 shows the graphical illustration of this investigation. The large white block represents all the problems that are identified. The green block groups the shortcomings that can be improved by the WMA technology and the blue block groups the shortcomings that can be improved by RA technology. The red block shows the shortcomings that can be improved by both technologies. This method helps to identify what shortcomings can be improved by which technology, which life cycle phase these improvements occur in as well as in what category they are (environmental, quality, cost and health). This helps to narrow down the elements that will be further investigated and analysed in this study.

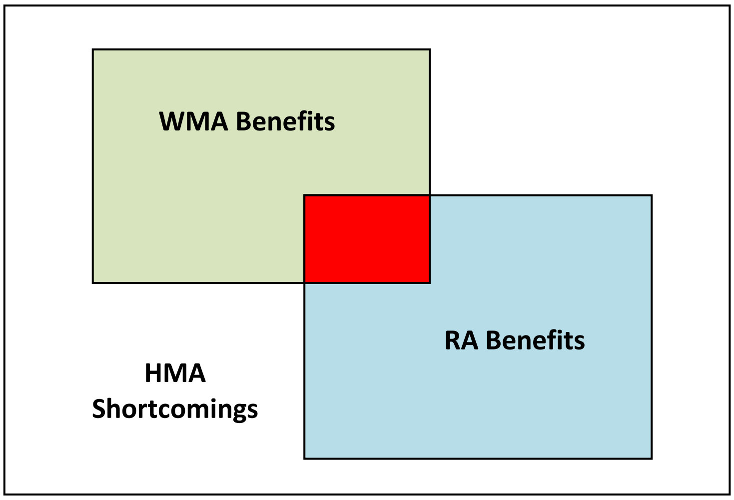

Figure 2: Benefit-Solution Diagram

2.3.1 HMA Shortcoming Identification

The life cycle of HMA must be defined and investigated before the potential shortcomings of HMA can be identified. Figure 3 shows a breakdown structure of the life cycle of HMA. Figure 3 indicates that five primary phases exist in the HMA's life cycle. These five phases form the basis for the identification of shortcomings with HMA and are each investigated separately.

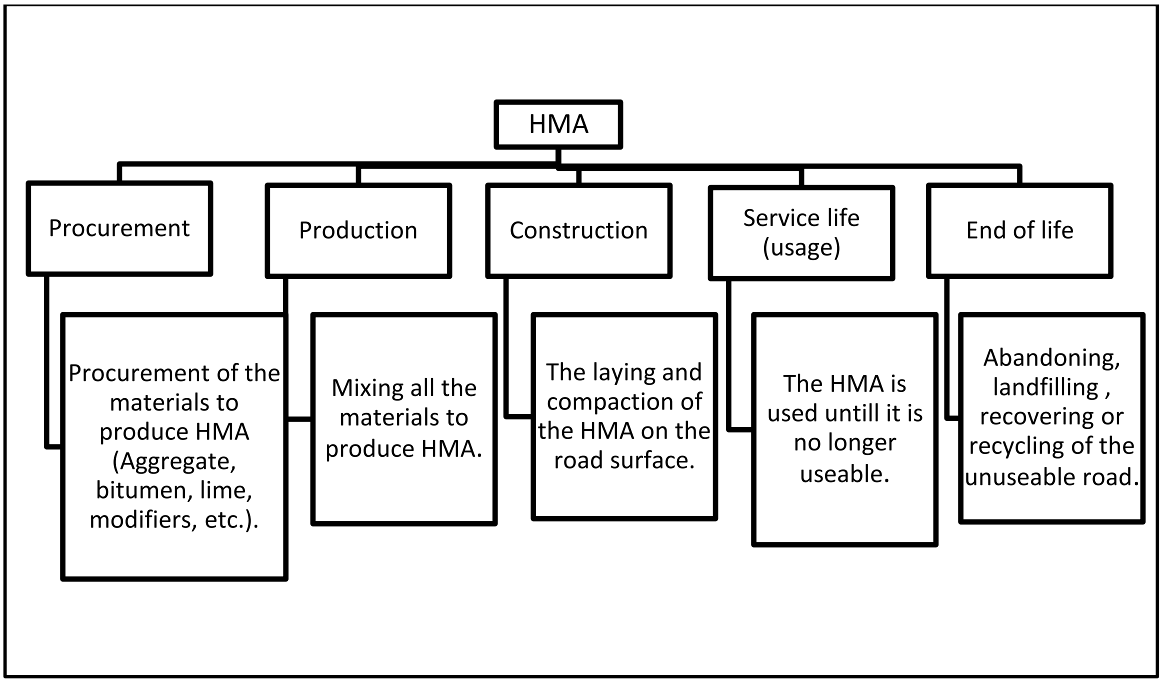

Figure 3: HMA Life Cycle

(Vidal et al., 2013)

The following paragraphs identify and list the shortcomings that can potentially be improved by the integration of improved life cycle phases as well as by applying new technology. The criteria for the shortcoming identification are that the shortcomings must fall under one of the following categories. These categories are selected to set boundaries to the shortcoming identification.

- Quality shortcomings,
- Environment shortcomings,
- Health shortcomings,
- Cost shortcomings.

The intent of the shortcoming identification is not to identify every shortcoming of HMA but rather to point out some of the most significant shortcomings where improvement is possible. The following paragraphs identify shortcomings in the five different life cycle components defined in Figure 3.

i. Procurement Shortcomings

The procurement of HMA materials consist of the extraction of minerals from the earth (aggregate) and transporting it to a crusher where it is crushed into the grading that is required by the HMA mix design. Bitumen is procured from an oil refinery as an end product of fuel manufacturing (Sabita, 2008). The procurement of these materials has some problem areas. These areas are determined through literature and are discussed below.

The availability of aggregate and bitumen is a problem as fuel prices increase, the distance between the procurement source and the project plays a more significant role (Taute et al., 2007). The availability of a quarry to extract aggregate is also a problem as quarries can only be established where the appropriate geological characteristics exist. The quality of the aggregate that's extracted from a quarry is also important as it can have an effect on the quality of the asphalt (Taute et al., 2007).

According to the February 2008 issue of AsphaltNews published by the South African Bitumen Association (Sabita) the price of bitumen and crushed stone (aggregate) shows a continuous increase. The bitumen price increase goes together with the dollar price of crude oil as well as the Rand/Dollar exchange rate (Sivan & Matthew, 2009). Figure 4 shows the cost index increase of bitumen and aggregate from 2001 to 2008. The increase of these materials increases the cost of HMA.

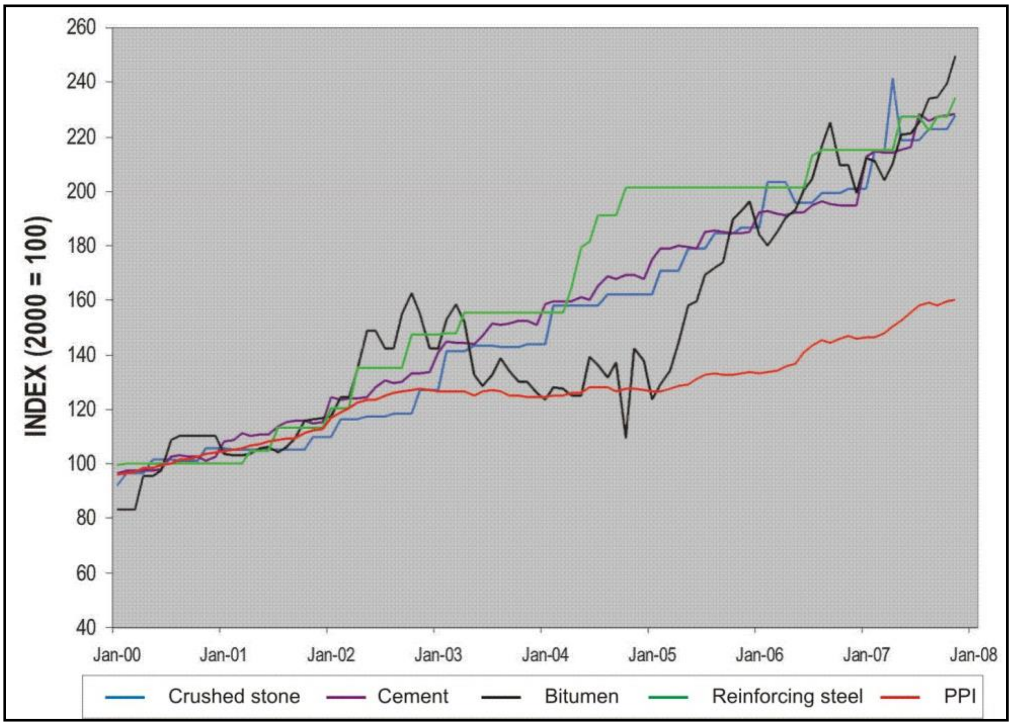

Figure 4: Bitumen and Crushed Stone Cost Index

New construction and maintenance of infrastructure demand more aggregate. This demand increase has a negative effect on the environment. Quarries create holes and depressions on the earth's surface. These were usually used to dump solid waste which caused even further damage to the environment. This aggregate extraction causes noise, air and water pollution, thus causing social and environmental problems. (West & Kyuho, 2006)

As a result of the manufacturing of bitumen as an end product of fuel manufacturing, it has a harmful effect on the environment as it produces emissions that release carbon dioxide (CO_2) into the atmosphere. With the increase of the world's population the demand for infrastructure is also increased. The use of bitumen also increases as the infrastructure demand increases, thus more damage to the environment. (Kennepohl, 2008)

The shortcomings that are identified in the procurement process are therefore:

- Availability of the aggregate,
- Quality of the aggregate,
- Cost increase of bitumen,
- Cost increase of aggregate,
- Negative environmental impact of extracting aggregate,
- Negative environmental impact of producing bitumen,
- Noise caused by aggregate extraction.

ii. Production Shortcomings

The asphalt production process has become extremely specialized. Asphalt is produced in asphalt production plants. There are currently two types of plants namely the batch plant and the drum plant. These plants are closely monitored and have to maintain and comply with vigorous quality specifications, safety and environmental regulations. In the asphalt production industry today it takes only three to five people to operate a modern plant (European Asphalt Pavement Association (EAPA), 2011).

During the asphalt production process the following materials (ingredients) are kept on the plant premises: bitumen, aggregate, lime as well as in some cases the Reclaimed Asphalt (RA). Bitumen is stored on site in large tanks and kept to a temperature of between 150°C and 180°C. It is kept at this temperature to ensure that the bitumen's viscosity is low and can thus be pumped through isolated pipes into the plant. The aggregate (sand, gravel and dust) is kept on different stockpiles which are arranged according to different aggregate sizes. The RA is also kept on its own stockpile. These materials are mixed together in a mixing drum at temperatures of 150°C and 190°C. (European Asphalt Pavement Association (EAPA), 2011)

The bitumen becomes hazardous when it is heated to these high temperatures in the mixing drum. Health issues caused by the heating of bitumen include (Bothma, 2011):

- Bitumen fumes, hot bitumen and cold bitumen cause irritation on the skin.
- Continuous inhalation of bitumen fumes can lead to an irritated nose and throat. A lengthy exposure can even cause headaches, dizziness and nasal congestion.
- Chronic exposure may cause serious health problems such as: Darkening of the skin and sensitization of the skin, chronic bronchitis, hoarseness and fatigue.

According to a study done by the National Asphalt Pavement Association (NAPA) the amount of emissions produced by an asphalt plant during production is directly linked to the temperature at which it is produced (National Asphalt Pavement Association, 2011). The temperature of the asphalt production process can thus be seen as a potential problem as it is very high. Another problem caused by the burner is noise pollution. The burner flame (along with the exhaust fan) produces the most noise and asphalt plants are placed near residential areas which causes social issues (Astec Inc., 2010).

According to Oliver Stotko (2011) of Carbon and Energy Africa (Pty) Ltd it is every country's responsibility to reduce the greenhouse gasses (GHG) emitted in their industries. He further states that the asphalt production process uses electricity and diesel which are both non-renewable resources and that the asphalt production process emits GHG. Stotko also indicated in his study that a reduction in the GHG and the use of non-renewable resources are possible. (Stotsko, 2011)The current increase in fuel prices also creates a problem for the production process as their fuel consumption is high.

Following the proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04) quality control was identified as one of the factors that cause failures in South African roads (Liebenberg et al., 2004). Quality control is one of the most important aspects of asphalt production and construction (Liebenberg et al., 2004). If insufficient quality control was applied to the production of a well-designed HMA mix the asphalt will still fail.

The shortcomings that are identified in the production process are therefore:

- High production temperature that causes high levels of hazardous emissions,
- The health risks to the labour force during the heating of bitumen,
- The noise pollution causes social and health problems,
- The fossil fuel combustion during the mixing process,

- The improvement of the quality control of the production process,
- The increasing cost of fuel.

iii. Construction Shortcomings

The HMA construction phase includes the laying of the asphalt on the road surface and the compaction of the HMA to the correct density (Vidal et al., 2013). The HMA is laid on the road surface by using a paver. A paver is a machine that is fed HMA from a truck and then spreads it evenly across the road surface while moving forward. The paver uses the latest technology to ensure that the width and the depth of the asphalt layer are correct (National Asphalt Pavement Association, 2011). The compaction process involves the use of multiple rollers to compact the HMA to the right density. These rollers normally include: Steel wheeled roller, pneumatic roller and a three point roller. The laying and compaction of the HMA consumes diesel (pavers, rollers) which as mentioned earlier is a non-renewable energy source that produces carbon dioxide (CO_2) during combustion and thus has a negative impact on the environment (Cerea, 2010).

The transport of the HMA to the construction site allows the asphalt to cool down and to reduce the amount of fumes produced. The workers that are part of the construction process do however stand a larger chance of exposure to the bitumen fumes (National Asphalt Pavement Association, 2011). The construction process has a team of workers that are directly exposed to the laying and compaction of the HMA. They are: paver operators, screed operators, rakers, labourers, foremen and roller operators (National Asphalt Pavement Association, 2011). The temperature of the HMA is thus a health issue to the construction team.

The quality during road construction is controlled by measuring certain volumetric parameters (Example: Densities and air voids) on a regular basis during construction. One of the factors that impact these volumetric parameters is the compaction temperature, thus the temperature at which the HMA is laid on the road surface (Saedi, 2012). The compaction temperature control can thus be identified as a potential problem.

The shortcomings that are identified in the construction process are therefore:

- Exposure to bitumen fumes by workers,
- Compaction temperature control,
- The use of non-renewable energy sources,
- The increase cost of fuel.

iv. Service Life Problems

The service life of HMA is defined as the period after the asphalt is compacted to the day it is disposed of or rendered unusable (the end of its service life). During this period most failures are attributed to premature failures of the asphalt layer. According to a study by Liebenberg (2004) these premature failures are caused by one of the following or a combination of them:

- Mix design,
- Manufacturing or
- Paving operation.

There are thus not direct problems that can be improved during the life span (in-service) of the HMA. Problems are caused by earlier processes in the life cycle. According to Liebenberg (2004) the failures that have been encountered in South Africa over the last few years are:

- Permanent deformation,
- Cracking
- Loss of surface texture (smoothing),
- Loss of surface aggregate,
- Stripping,
- Disintegration of the layer,
- Bleeding and flushing.

These failures cause the asphalt to fail to meet its designed purpose. This is thus a product quality impact. This quality impact leads to an increase in road maintenance cost as the asphalt surface requires more regular maintenance and rehabilitation.

The shortcomings that are identified in the HMA's life-span are:

- The quality of mix designs that can reduce the service life,
- The quality control during manufacturing and production,
- The secondary problem to the poor asphalt mix quality is a reduction in service life and an increase in the maintenance costs.

v. End of Life Problems

The end of the service life of HMA is defined as the period when the asphalt is rendered unusable and no longer fulfils its purpose for which it was designed. The problem that occurs is what to do with the aged and unusable asphalt. The decision must be made if it is abandoned, land filled, recovered or recycled. (Vidal et al., 2013)

The shortcoming that is identified in the HMA's end of life is:

- The management of aged and unusable asphalt at the end of its service life.

Problem Summary:

Table 4 summarises the shortcomings that have been identified and which form part of the evaluation of the WMA and RA technology.

Table 4: HMA Problem Identification

HMA Life Cycle Phase	*Shortcomings*	Category
Procurement	Availability of the aggregate.	Environmental
	Quality of the aggregate.	Quality
	Cost increase of bitumen.	Cost
	Cost increase of aggregate.	Cost
	Negative environmental impact of extracting aggregate.	Environmental
	Negative environmental impact of producing bitumen.	Environmental
	Noise caused by aggregate extraction.	Health
Production	High production temperature that causes high levels of hazardous emissions.	Environmental
	The health risks to the labour force during the heating of bitumen.	Health
	The noise pollution causes community problems.	Health
	The fossil fuel combustion during the mixing process.	Environmental
	The improvement of the quality control of the production process.	Quality
	The increasing cost of fuel.	Cost
Construction	Exposure to bitumen fumes by workers.	Health
	Compaction temperature control.	Quality
	The use of non-renewable energy sources.	Environmental
	The increase cost of fuel.	Cost
Service life (usage)	The quality of mix designs that can reduce the service life.	Quality
	The quality control during manufacturing and production.	Quality
	The secondary problem to the poor asphalt mix quality is a reduction in service life and an increase in the maintenance costs.	Cost
End of Life	The management of aged and unusable asphalt at the end of its service life.	Environmental/Cost

2.3.2 WMA and RA Technology Benefits

This section describes the principle behind WMA and RA technologies and summarises the possible benefits that can be gained from applying the WMA and RA technologies. These benefits are obtained from literature. Tables 5 and Table 6 show these benefits.

i. <u>RA Technology</u>

The following statement is made in a literature review of reclaimed asphalt that was published by the Illinois Centre for Transportation:

"Recycling hot mix asphalt (HMA) material results in a reusable mixture of aggregate and asphalt binder known as reclaimed asphalt pavement (RAP). Recycling of asphalt pavements is a valuable approach for technical, economical, and environmental reasons. Using RAP has been favoured over virgin materials in the light of the increasing cost of asphalt, the scarcity of quality aggregates, and the pressuring need to preserve the environment. (Al-Qadi et al., 2007)*"*

The use of RA in HMA involves a process that rejuvenates the properties of the recycled binder to allow it to be used with new virgin binders.

There are two main engineering properties that are affected by the use of RA in HMA. These are the gradation of the asphalt and the binder content (as well as the penetration and viscosity of the binder) (Al-Qadi et al., 2007):

- Gradation: The gradation of RA is normally finer than virgin aggregates because of the mechanical degradation that occur when the asphalt is removed from the pavement and when it is processed through a crushing and screening process.
- Binder content: RA normally contains between three and seven percent binder. This binder has however aged which has caused it to become harder (increased stiffness) and the viscosity is also lowered which leads to a lower penetration grade than the virgin binders. This means that the binder obtained through RA has changed to a different grade of binder.

The use of aged binder can severely influence the properties of the blend with a virgin binder. However it has been determined that aged binder does not influence the grade of the virgin binder for mixes with less than 20% RA. For mixes with more than 20% RA a rejuvenation process has to occur. Modifiers have therefore been developed that can rejuvenate the aged binder to the same specifications as the virgin binder, thus reducing the aging of the old binder during the mixing process. These modifications normally include softening and rejuvenation agents. Softening agents reduces the viscosity of the binder. The rejuvenation agents restore the physical and chemical properties of the old binder. It is a complicated process to ensure that the blend of old and new binder meets the binder specifications of the required HMA mix. (Al-Qadi et al., 2007).

Virgin aggregate and RA aggregate have more or less the same durability properties. The RA thus satisfies the required durability specifications. Virgin aggregate is added to reduce the amount of RA in the mix as well as to improve the gradation where necessary. (Al-Qadi et al., 2007)

Table 5 lists the benefits of using RA in HMA mixes.

Table 5: RA Benefits

	Benefit	**Source**
1	Reduces the use of natural resources.	(Colorado Asphalt Pavement Association (CAPA), 2009)
2	Reduces the use of binder which reduces the dependence on foreign oil supplies.	(Grobler et al., 2012)
3	The design of RA pavement can use the same structural equivalency factor as normal mixes.	(Colorado Asphalt Pavement Association (CAPA), 2009)
4	Reduces the concerns of sufficient stockpiling area and elimination of old material.	(Colorado Asphalt Pavement Association (CAPA), 2009)
5	Reduces the cost of HMA material production.	(Colorado Asphalt Pavement Association (CAPA), 2009)
6	Reduces the fast depletion of aggregate stockpiles.	(Grobler et al., 2012)
7	Reduction in fuel consumption during construction.	(Grobler et al., 2012)

ii. <u>WMA Technology:</u>

Warm Mix Asphalt (WMA) is defined by the Best Practice Guideline for Warm Mix Asphalt published by the Southern Africa Bitumen Association (Sabita) as:

"Mixtures of aggregate, bituminous binder and mineral filler, where a WMA Technology is employed to enable the mix to be manufactured and paved at a significantly lower temperature than HMA, with its quality and performance being equal to or even exceeding that of HMA. (Lewis et al., 2011)*"*

The term WMA technology does not only include the additive added to the mixing process but it includes the whole process of creating asphalt at a lower temperature. WMA technology's main goal is to produce asphalt at a lower temperature with the necessary aggregate coating as well as the required workability. This is normally done by using one of the following WMA techniques (shown in Figure 5). (Mbaraga, 2011)

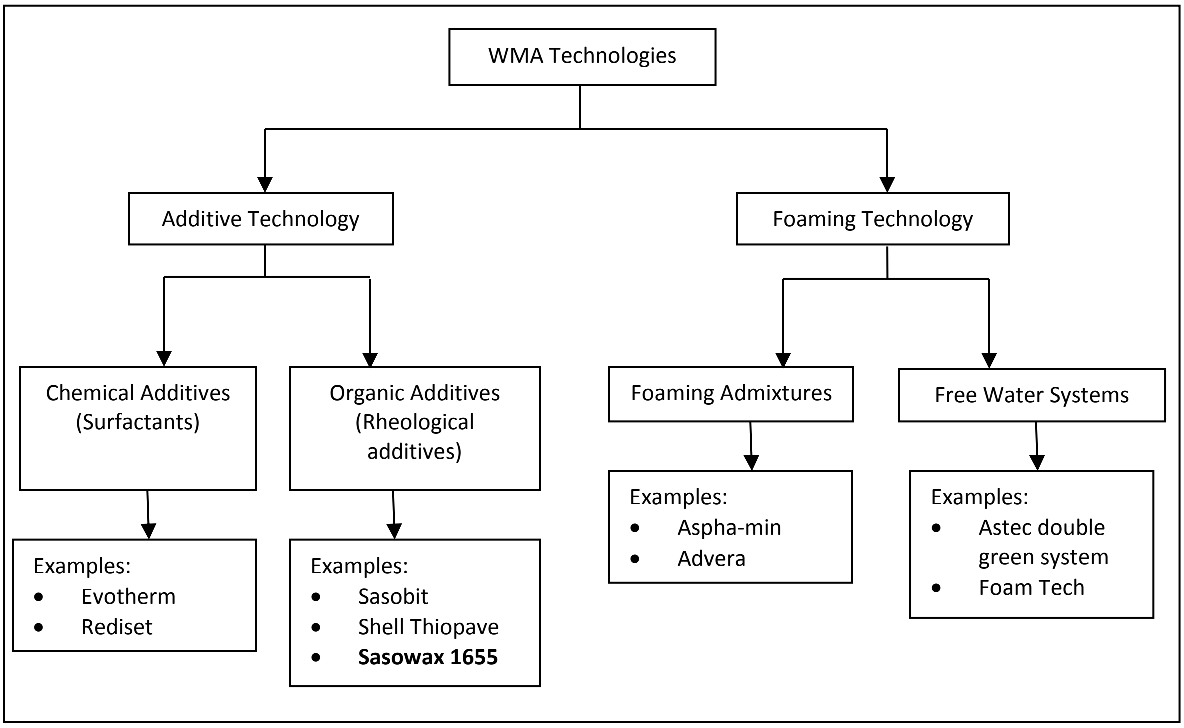

Figure 5: WMA Technologies

Figure 5 shows that WMA technologies can be divided into two types, namely: additive and foaming technology.

Foaming technologies: Water, a chemical water modifier or moist fines are injected into the hot binder which causes the binder to expand and form foam. This expanded binder's surface area is increased and its viscosity is reduced, this allows it to coat the aggregate at lower temperatures (Lewis et al., 2011). The foaming technologies can further be divided into foaming admixtures and free water systems. These will however not be discussed as the technology used in this study is an additive technology.

Additive technology:

WMA technologies can be added to the mixing process by the following methods (Lewis et al., 2011):

- It can be added as a ready-to-use binder. The additive is thus already mixed into the binder before it enters the mixing drum. This ensures homogeneity of additive in the mix.
- It can be added directly into the mixing drum. The problem with this is to ensure that the additive is mixed homogeneously in the drum.

WMA technologies have the following effects on the HMA (Lewis et al., 2011):

- Reduces the viscosity of the binder. This enhances the ability of the binder to coat the aggregate. High temperatures that are normally required to reduce viscosity are no longer required because of this additive.
- Reduces the friction between the particles in the mix which allows the asphalt to be compacted easily and thus at lower temperatures. This allows for lower paving temperatures and creases a longer compaction window.

Additive WMA technology can be divided into chemical and organic additives.

Chemical modifiers:

These modifiers reduce the internal friction between the mix particles that allows it to be compacted at lower temperatures. These modifiers do not however reduce the viscosity, but only the internal friction (Lewis et al., 2011).

Organic (Rheological) modifiers:

Additive WMA technologies use waxes to alter the rheological properties of the binder which reduces the viscosity of the binder. This leads to the improved aggregate coating and better compaction at lower temperatures (Lewis et al., 2011).

The waxes that are commonly used are (Mbaraga, 2011):

- Fischer Tropsch wax (Sasobit®),
- Montan wax (Aspaltan – B),
- Fatty acid amides (Licomont BS 100),
- Blends of Montan wax and Fatty acid amides.

Sasobit is the most common organic WMA additive used. It has a low viscosity at high temperatures and a high viscosity at low temperatures. Sasobit focuses on the binder-flow and thus reduces the viscosity of the binder at low temperatures (Mbaraga, 2011).

These days WMA additives are modified to enable the use of modified WMA pavements. Products like Sasoflex, Sasowax 1655 and SasolWaxFlex™ are Sasobit products that are modified for certain performance specifications. Sasowax 1655 is used in this study and is modified for high performance for high RA applications (Lewis, 2011).

Table 6 lists the benefits that can be obtained by using WMA technology.

Table 6: WMA Benefits

	Benefit	**Source**
1	It reduces the emissions of the plant which reduces greenhouse gasses. This reduction is made because of the reduction in mixing temperature.	(Lewis et al., 2011)
2	The use of non-renewable fossil fuels is also reduced due to the lower mixing temperature requirement.	(Lewis et al., 2011)
3	Reduction of the burning of fossil fuels and the lower plant temperatures reduces the amount of emissions, dust and fumes which improves the environment for workers as well as neighbouring urban areas.	(Lewis et al., 2011)
4	Asphalt plants can be erected closer to urban areas to supply asphalt to urban road networks due to the lower emissions. This reduces transportation costs to the paving site.	(Lewis et al., 2011)
5	The WMA technologies improve the workability of the asphalt and thus help with the compaction of more stiff mixes that are normally more difficult to compact.	(Lewis et al., 2011)
6	The longer cooling period of WMA allows paving to be done in colder climates. It thus creates a longer compaction window as it cools down slower and compaction can be done over a longer period after production.	(Lewis et al., 2011)
7	In cases where long hauling is required the mixing temperature of WMA can be increased to normal HMA temperature which allows for a very long cooling period and ensures the right temperature for compaction.	(Lewis et al., 2011)

2.3.3 Discussion of the Benefit-Solution Investigation

Table 7 shows the results of the benefit-solution investigation. 21 shortcomings were identified through the five life cycle phases of HMA (through literature) of which 14 can be positively impacted by the RA and WMA technology. This indicates that these technologies are beneficial and that they are appropriate technologies for this study.

The only HMA life cycle phase that doesn't get directly affected by these technologies is during the service life of the HMA. It is however noticeable that literature indicates that the WMA has the same or even better quality performance than the HMA.

After studying the results the following factors have been identified for further investigation and analysis.

WMA Technology:

The following aspects were identified with regards to the potential impact of WMA technology on the asphalt life cycle:

- It can have a positive impact on the ***production*** and the ***construction phases*** of HMA.
- It can have a positive impact on the ***cost, environmental*** and ***health*** aspects of these phases.
- The impact on the ***service life performance*** has to be considered at as it may vary from HMA.

RA Technology:

The following aspects were identified with regards to the potential impact of RA technology on the asphalt life cycle:

- It can have a positive impact on the ***procurement*** and ***end of life phases*** of the HMA.
- It can have a positive impact on the ***cost*** and ***environmental*** aspects of these phases.

The benefit-solution investigation shows which aspect of the HMA life cycle is going to be further investigated and analysed. It has been identified that the five HMA life cycle phases are all impacted by the technologies. The bulk of these impacts are environmental and cost related. This also shows that both these technologies can be beneficial for the South African asphalt industry. The following section looks at prior research that has been done to investigate these cost and environmental impacts.

Table 7: Benefit-Solution Results

HMA Life Cycle Phase	Shortcomings	Category	RA	WMA
Procurement	Availability of the aggregate.	Environmental	X	
	Quality of the aggregate.	Quality		
	Cost increase of bitumen.	Cost	X	
	Cost increase of aggregate.	Cost	X	
	Negative environmental impact of extracting aggregate.	Environmental	X	
	Negative environmental impact of producing bitumen.	Environmental	X	
	Noise caused by aggregate extraction.	Health		

Table 7: Benefit-Solution Results (continues)				
Production	High production temperature that causes high levels of hazardous emissions.	Environmental		X
	The health risks to the labour force during the heating of bitumen that causes bitumen fumes.	Health		X
	The noise pollution causes community problems	Health		
	The fossil fuel combustion during the mixing process.	Environmental		X
	The improvement of the quality control of the production process.	Quality		
	The increasing cost of fuel	Cost		X
Construction	Exposure to bitumen fumes by workers.	Health		X
	Compaction temperature control.	Quality		
	The use of non-renewable energy sources.	Environmental		X
	The increase cost of fuel.	Cost		X
Service life (usage)	The quality of mix designs that can reduce the service life.	Quality		
	The quality control during manufacturing and production.	Quality		
	The secondary problem to the poor asphalt mix quality is a reduction in service life and an increase in the maintenance costs.	Cost		
End of Life	The management of aged and unusable asphalt at the end of its service life.	Environmental/Cost	X	

2.4 Prior Research

The following studies were used to obtain knowledge of methods to analyse and further investigate the impacts of WMA and RA technologies regarding cost and environmental aspects. It was also used to find out what has been researched in this field. This prior research serves as a basis and a guide for the further investigation of this study.

- **Warm Mix Asphalt Investigation by Martins Zaumanis *(Zaumanis, 2010):***

The study by Zaumanis (2010) was done by the Technical University of Denmark in cooperation with the Danish Roads Institute. The study focuses on the comparison of the performance between WMA and HMA. Laboratory tests were done on two WMA technologies (Rediset and Sasobit) which indicated that it has an effect on the properties of the bitumen. The study also indicated that the WMA can be produced at a temperature as low as 125°C without significantly changing the stiffness and permanent deformation in comparison to HMA.

The study includes a Life Cycle Inventory Assessment (LCIA) that calculates the energy consumption of the WMA processes as well as the conventional HMA processes. The LCIA included the following processes of the asphalt:

- Production process that includes the plant production as well as the material procurement (RA, WMA additive, fibre, bitumen, filler and aggregate).
- Asphalt laying and compaction.

The LCIA included the use of RA into its experimental considerations (up to 40% of the mix). The results indicated that the energy savings is between 5% and 18% when using WMA technologies (with varying RA usage 0% - 40%). The LCIA did however not include the service-life energy consumption which will mainly consist of maintenance and rehabilitation. This assessment's calculation was done with energy data from Denmark which includes energy sources such as wind power, natural gas, oil and some other sustainable energy. This is significant as South Africa's energy sources differ from Denmark's energy sources. This can have an impact on the results of an environmental assessment as Denmark uses more sustainable energy sources than South Africa.

The study also included a brief cost comparison between WMA and HMA. The potential cost savings identified by this study are: energy cost savings (electricity, fuel, etc.) and compaction savings (less rollers required for compaction). Three cost increases were identified: plant modifications, cost of the WMA additive and possible cost of technology licensing. No life cycle cost assessment was done.

This study provides valuable literature on WMA technologies and their impact on a conventional HMA. The study also provides a practical method (LCIA) of analysing the environmental impact of the WMA technology.

- **New Developments with Half Warm Foamed Bitumen Asphalt Mixtures for Sustainable and Durable Pavement Solutions by M.F.C. van de Ven, B. W. Sluer, K.J. Jenkins, C.M.A. van den Beemt *(Van de Ven et al., 2012):***

This study by Van de Ven (2012) was done by the Delft University of Technology in the Netherlands. This study conducts a Life Cycle assessment (LCA) that was done in the Netherlands on half warm asphalt mixes (half warm mixes: 90°C - 100°C). The compaction of these mixes as well as the managing of this compaction is also discussed.

The study discusses the use of a Dutch computer program called Dubocalc that calculates the relevant environmental impacts and then converts it to a monetary value. This program can thus quantify the costs of environmental impacts.

A LCA is done on half warm mix asphalt. The LCA includes the following processes and phases: production, transport, construction and recycling of the asphalt. The results of the LCA are then expressed as the impact they have on different impact categories, namely: global warming, ozone layer depletion, eutrophication, aquatic ecotoxicity, human ecotoxicity, non-hazardous waste, hazardous waste, energy, etc.

This study provides another method of determining the environmental impact of HMA technologies. It also does not include the environmental impact of the service-life of the asphalt. The method used to convert energy consumption to a monetary value is relevant to this study as cost and environmental impact are considered.

- **Combining LCC and Energy Consumption for Enhancing Decision Making Regarding Rehabilitation Options *(Jenkins & Collings, 2011):***

A study by Jenkins and Collings (2011) was done at the Stellenbosch University and UCD Technology / Loudon International. This study investigates the rehabilitation options of HMA during its service life. Four rehabilitation solutions are investigated, namely:

- Patch and overlay,
- Mill and replace,
- Recycle / Cement Stabilise the Existing Pavement and Overlay,
- Recycle / Bitumen Stabilise the Existing Pavement.

Life cycle costing (LCC) is done on the solutions by quantifying the construction processes needed to maintain the same level of serviceability of the roads for their service life (20 years). The study further quantifies the environmental consequences of the different solutions by measuring the energy consumption of each solution. There are thus two parameters by which the solutions can be compared, the LCC and the energy consumption analysis.

The most valuable part of this study is the investigation into the quantifying of the combined impact of the cost and energy impact. The study provides a model that combines these two parameters and provides a way to evaluate different pavement structures in a way that not only cost is involved but also integrates the environmental impact into the decision making process. The model thus creates a connection between these two parameters to provide a more holistic approach to decision making. This study also quantifies the energy consumption of the maintenance and rehabilitation phase of the asphalt life cycle which is relevant as it is also going to be done I this study.

- **Preventive Maintenance Treatments on Road Pavements: Multi-Approach Life-Cycle Assessment by Paolo Cerea *(Cerea, 2010):***

A study by Cerea (2010) was performed at the school of engineering (road infrastructure department) in Milan, Italy. This study also investigates the maintenance and rehabilitation measures. It focuses on determining the cost-effectiveness and sustainability of different rehabilitation methods.

This study incorporates the use of RA and WMA technology. The data procurement for this study is very scientific and detailed. The environmental impact assessment includes the material procurement, asphalt production, transportation as well as service-life rehabilitation and maintenance. The study investigates nine different rehabilitation solutions. The study spends a substantial amount of time on the determining of the asphalt laying and compaction. The emissions of different machines are thoroughly investigated.

The study also provides a life cycle cost analysis that is specifically based on the rehabilitation and maintenance costs. A basic comparison model is also included to show the cost-sustainability relationship though a cost-benefit analysis.

This study concludes by providing a case study that evaluates the cost and environmental impact of different rehabilitation solutions (which are then compared to each other). This case study is based on a specific project and the data is thus gathered from the specific project. It is however useful as different rehabilitation methods are compared to the project specific data.

2.5 Conclusion

After a proper background of HMA was given in this chapter the HMA life cycle phases were identified, namely:

- Material procurement,
- Asphalt production,
- Construction,
- Service life (usage),
- End of life.

Shortcomings for possible improvement were identified and listed in each of these phases. These shortcomings were also categorised in the following categories: environmental, quality, health and cost. The benefits of RA and WMA technologies were also listed from literature. The benefits were compared (through a benefit-solution investigation) to the listed shortcomings to determine the following:

- If the technologies can have a positive impact on the HMA life cycle?
- Which life cycle phases can be affected by the technologies?
- Which categories are affected by the technologies?

This was done to narrow down the relevant areas that will be investigated further in the study. 21 shortcomings were identified throughout the HMA life cycle of which the technologies provide benefits to 14 of them, which indicates that the combination of these two technologies can be potentially beneficial to the whole HMA life cycle. Table 8 lists the identified areas:

Table 8: Narrowed Down Parameters

Technologies	**HMA life cycle phases affected**	**Categories identified**
Warm Mix Asphalt technology	Procurement	Cost impact
Reclaimed Asphalt	Production	Environmental impact
	Construction	
	Service life	
	End of life	

Table 8 summarises the parameters that were identified and which will be investigated further in this study. It was found that the RA technology can be beneficial for the procurement and the end of life phase and the WMA technology can be beneficial for the production and construction phase. From literature there was no clear benefit from these technologies on the service life phase. From the prior research studied in Section 2.4 it was however determined that the service life is a primary role player in the quantifying of the environmental and cost impact as it includes the rehabilitation and maintenance of the asphalt (which is cost and energy consuming processes). It has thus been decided to add it to the parameters that will be investigated further in the study.

Table 8 also lists the categories that were identified to be investigated further, cost and environmental impact. It must be noted that the health category has not been categorised on its own as the main health issues that were identified were caused by emissions and bitumen fumes. These are also environmental shortcomings and are thus combined with the environmental category.

After narrowing down the aspects that will be investigated further in the study (as listed in Table 8), methods of analysing these aspects have to be determined. After studying the prior research in Section 2.4 it is concluded that a life cycle analysis (LCA) and a life cycle cost analysis (LCCA) will be conducted to investigate the impact of these technologies on cost and environmental aspects. These studies confirmed the importance of the five HMA life cycle phases to these analyses as the studies have proved that all these phases have an effect on the cost and environmental aspects of the HMA. The methodology of the analyses of (Zaumanis, 2010) will be implemented as it is laid out in a logical way. The analysis is also based on the ISO 14040 (International Organization for Standardization, 1997) document which provides extensive guidelines to conduct a LCA. This methodology will be modified by integrating some of these useful aspects of the other studies as each of them addressed the analyses in different ways and included detailed information for different phases.

These analyses will be done on a case study of a current project in South Africa. The study by (Cerea, 2010) used a case study of a local project in Italy which is beneficial for local practitioners as the data used for the analysis is procured locally and local asphalt procurement, production and construction methods are analysed which may differ from international methods.

Whilst this chapter mostly focuses on the benefits of the technologies to narrow down the study's scope, Chapter 3 investigates the use of these technologies in South Africa. Chapter 3 includes interviews with various role-players in the asphalt production and application industry. These interviews will be used to identify the risks involved in applying these technologies as well as to determine the level of use to date in South Africa. The experimental considerations for the analyses are discussed in Chapter 4.

CHAPTER 3: RISK IDENTIFICATION OF WMA AND RA TECHNOLOGY IN SOUTH AFRICA (SA)

3.1 Introduction

Chapter 3 investigates the potential risks involved in using these technologies in South Africa. Identifying these risks is made difficult by a lack of literature that shows the risks of implementing these technologies in South Africa. Literature tends to focus on the potential benefits of the technology and not the risks that can be created by using these technologies. It has thus been decided to conduct a series of interviews with key role-players and practitioners of these technologies in South Africa. These practitioners include:

- contractors,
- asphalt suppliers,
- clients,
- consulting engineers.

These selected role-players and practitioners are considered to be specialists in this technology field. It has been decided to use interviews instead of questionnaires as not many practitioners are aware of these technologies or have any work experience with these technologies. This risk identification is thus based on expert opinions of these technologies in South Africa.

The aims of this chapter are:

- To provide a brief literature background of the use and progress of RA and WMA technology in South Africa.
- To properly define the goals of the interviews and to create a set of questions that extract the most relevant information from the experts.
- To identify the key role-players that will form the specialist opinion and to conduct the interviews in a proper and professional manner.
- To collect the interview data and to make sensible and insightful conclusions from the specialist feedback.
- To investigate the growth of these technologies in South Africa.
- To investigate the regional interest in applying these technologies.
- To identify the risks involved in using RA and WMA technology in South Africa.

3.2 Brief Background

The following sections provide a brief background of the use of these technologies in South Africa. It discusses the progress made in the integration of these technologies in the South African Industry.

3.2.1 Use of RA in South Africa

The first use of RA in South Africa was in the 1980's when it was used in two large projects one on the Van Reenen's Pass on the National Route 3(N3) highway and the other one between Paarl and Kraaifontein on the National Route 1(N1). In 1984 a work group was formed under the Council of Scientific and Industrial Research (CSIR) which produced a number of papers on RA which further led to the writing of recommended techniques in 1996 which was revised in 2009. (South African Bitumen Association (Sabita), 2011)

During the 1990's there was a slump in the RA industry and interest was lost due to market related factors. However in the last couple of years this technology has started to receive much attention as the world put more emphasis on environmental conservation and carbon footprint reduction. (South African Bitumen Association (Sabita), 2011)

Brian Neville, technical manager at Much Asphalt (Pty) Ltd, the largest supplier of cold and hot mix asphalt in Southern Africa stated that:

"*We can use about 95% of the recycled material in our various asphalt mixes where recycled asphalt (RA) is included in the project specifications. This, in turn, decreases the virgin raw material input into the plant, saving on the cost of raw materials and reducing the pressure on our natural resources and our carbon footprint. Reclaiming asphalt material offers financial savings all-round in material costs, including asphalt binder, energy costs and total job costs. So everyone benefits, including the tax payer who ultimately pays for the building and maintenance of our roads*." (South African Bitumen Association (Sabita), 2011)

3.2.2 Use of WMA in South Africa

The first real involvement of South Africa in WMA came in 2008 when the Society for Asphalt Technology (SAT) held a seminar in Pretoria (9 July 2008). This seminar led to the formation of a task team called the Warm Mix Asphalt Interest Group (WMAIG) that was instructed to conduct the necessary research into WMA as well as to plan and manage trial test to determine the benefits of using WMA technology on South African roads. (Lewis et al., 2011)

The first two WMA trials were conducted in South Africa close to Durban at the following locations.

- Brackenhill Road, Waterfall, about 30km inland of Durban (2008),
- Leicester Road, Mobeni, Durban Industrial (2009).

The good results from these trials led to an expensive WMA trial on the Higginson Highway, Durban (2010). These trials were the largest asphalt trials ever done in South African asphalt history (Lewis, 2011). They posted the following goals to increase the boundaries of WMA in South Africa. (Lewis, 2011)

- To increase the quantity of RA usage;
- To lower the production temperature of HMA production,
- To use polymer modified binder in HMA production,
- To equal the performance and quality standards of conventional HMA.

This trial included extensive laboratory mix design trials, plant mix trials as well as main trials on the road. Some of these mixes included mixes with RA up to 40%, which is seen as very high even in world standards. These trials produced positive results and increased the interest in WMA technology as a green engineering method in South Africa. Visits to European Union (EU) countries and a thorough literature review also contributed to current knowledge in South Africa on WMA. (Lewis et al., 2011)

After the success achieved through these trials (2008-2010) the eThekwini Municipality in Durban took the first step in allowing the permanent application of WMA. The municipality decided that WMA may now be used in future projects. The decision was based on the trial results that showed that the WMA is of the same quality as HMA and also led to the paving of 35 000 tons of WMA in this area. (Lewis & Naidoo, 2011)

Four years after the first trial had been laid it was inspected and the following results were found:

Brackenhill Road:

This trial section has the most challenging geometrical configuration and was also paved first in 2008. Apart from minor cracking and some damage caused by a drainage pipe problem, the WMA mix has also performed well. (Sabita, 2012)

Leicester Road:

This trial section carries the heaviest load of the three trial sections. This road was paved with three different mixes which included a HMA mix and a WMA mix layer. After an investigation it was noted that the HMA arguably performed worse than the WMA mix. There were some bleeding but no rutting was recorded which under heavy traffic is very good. (Sabita, 2012)

Higginson Highway:

The trial section of the Higginson highway is the trial section that carries the fastest traffic of the three trials. The highway was paved with a WMA base and was then covered with a non WMA surfacing layer. There is however no signs of failure to the surfacing which shows that the base layer is still in a good condition. (Sabita, 2012)

3.2.3 Conclusion

By looking at the progress that is made by the South African asphalt industry to implement these technologies it is clear that there are benefits to the industry. It is however still important to identify the possible risks or consequences of using these technologies especially in the early stages of technology integration where there are still some unknowns.

The next sections focus on the interviews that are conducted with RA and WMA technology specialists to identify possible risks of using these technologies.

3.3 Data Procurement Method

Two data procurement methods were considered for the procurement of data from role-players and practitioners of RA and WMA technology. They are:

- ***Personal interviews:*** This method includes the identification of the most appropriate interviewees. They are asked questions that are relevant to the research topic and their specialist opinion is recorded.
- ***Questionnaires:*** This method includes the distribution of a large number of questionnaires to as much as possible practitioners. These questionnaires normally require short answers that may include rankings and other numerical classifications. These questionnaires are then statistically analysed to obtain research results.

Personal interviews were selected as the method to procure risk related information from role-players and practitioners of RA and WMA technology in South Africa. This method was selected above the use of questionnaires. The following reasons are given to motivate the use of this method:

- The topic of the interviews (RA and WMA technologies) is only applicable to practitioners that have worked with these technologies. As knowledge of these technologies is specialised and not widely available among practitioners in South Africa, personal interviews can extract as much information as possible from practitioners.

- Much more information can be procured through personal interviews than questionnaires that are completed in a rush. The answers of the practitioners are thus elaborated and explained for a better understanding and eliminates "one word" answers.
- As the interviews' topic is specialised, the alternative approach of using questionnaires may be distributed to many practitioners that may not have worked with these technologies and may cause false or inaccurate feedback.
- The use of specialist interviews ensures that all the procured information can be seen as truthful and this eliminates the use of complicated statistical methods that are used to rectify possible faulty feedback from practitioners.

The following section discusses the criteria for the specialist selection process as well as the names and relevant experience of these experts in the field of RA and WMA technologies in South Africa.

3.4 Specialist Selection

The specialist identification and selection process was conducted in 2 phases. These phases are:

Phase 1: Consulting with some of the University of Stellenbosch's pavement research engineering staff, namely Prof. Fred Hugo and Prof. KJ Jenkins. An initial contact list was thus established. This contact list included specialists in the RA and WMA technology field.

Phase 2: The practitioners on the initial contact list were interviewed. At the end of the interviews the interviewees were asked to give the names of practitioners that can also make a contribution to the study. By doing this a list of specialists was created which acted as a reliable source of knowledge and information.

The interviews were conducted via e-mail. Feedback was generally received after the first e-mails were sent out. There were however follow-up e-mails that reminded the non-compliant practitioners of the interviews. Some practitioners that had been approached replied that they did not have sufficient knowledge to answer the questions. 18 practitioners had been approached of which nine was able to complete the interview. Four of the practitioners did not have sufficient knowledge of these technologies and five of them failed to conduct the interview (after a series of three follow-up e-mails).

The nine specialists that had been successfully interviewed are listed in Table 9.

Table 9: Specialist Contact List

	Name:	Current employment:	Contact details:
1	Jannie Grobler	Technical Executive at Arcuss Gibb Consultants	jgrobler@gibb.co.za
2	Arthur Taute	Managing Director at Vela VKE Consulting	Arthur.taute@smec.com
3	Lucas-Jan Ebels	Technical Director at UWP Consulting	lucase@uwp.co.za
4	Herman Marais	Technical Director at Much Asphalt	herman.marais@murrob.com
5	Wynand Nortjè	Technical Manager at National Asphalt	wynand@nationalasphalt.co.za
6	Deon Pagel	Commercial Manager at National Asphalt	deon@nationalasphalt.co.za
7	Tony Lewis	Tony Lewis Consulting	tonylcons@telkomsa.net
8	Jonathan Core	Jean Lefebvre (UK) Limited	jonathan.core@ringway.co.uk
9	Pieter Myburgh	Technical advisor to Sabita	pmyburgh@ffg.net

The experience in the asphalt industry of each specialist is listed below:

Jannie Grobler:

- Registered Professional Engineer.
- Airport Engineering at various airports.
- Pavement Engineer including various road rehabilitation designs, new pavement designs and special investigations.
- Bitumen and asphalt research at both the CSIR and Much Asphalt.
- Worked on more than 20 asphalt projects.

Arthur Taute:

- Former CEO of Vela VKE Consulting.
- Former Managing Director of VKE international.
- Chairman of the Group of Africa Member Associations (GAMA). GAMA is the African chapter of the International Federation of Consulting Engineers (FIDIC).
- Chairman of South African Bitumen Association's (Sabita) Technology Development Focal Point for more than 20 years.

Lucas-Jan Ebels:

- Technical Director of UWP Consulting.
- Member of the Society of Asphalt Technologists (SAT).
- Material engineer and pavement design specialist at UWP Consulting.

Herman Marais:

- Technical Director at Much Asphalt.
- Member of Sabita.
- Member of SAT and the Chairman of the Central Region.
- Member of the Warm Mix Asphalt Interest Group (WMAIG).

Wynand Nortjè:

- Technical Manager at National Asphalt.
- Instrumental with the development of the WMA implementation in South Africa and designed the first ever WMA mixes in South Africa.
- Member of the WMAIG.
- Member of SAT for more than 10 years.
- Since 1986 worked at the Transvaal Roads Department and later with Jeffares and Green Consulting Engineers.
- Member of numerous Sabita work groups.

Deon Pagel:

- A Director at National Asphalt.
- Responsible for the development and growth of the business through looking at opportunities across the board. This also involves being aware of new technologies and the alignment of the business with best practise at all times, hence also the involvement in WMA and RA.
- A Director of Sabita and currently Chairman of the Board.
- Member of SAT.

Tony Lewis:

- Over 40 years experience in the construction industry.
- Founder Member of SAT.
- Member of the WMAIG.
- Lead author for TRH21:2009 (Technical Recommendations for Highways) and Sabita Manual 32.

Jonathan Core:

- Divisional Manager at Jean Lefebvre (UK).

- This UK based company specialises in material design and performance testing, asset management, pavement engineering and technology transfer of products and processes (has transferred technologies to South Africa before).
- Over 18 years experience in the construction industry.

Pieter Myburgh:

- Technical advisor to South African Bitumen Association (Sabita).
- Was employed by the Cape Provincial Administration's (CPA) Roads Department where he was the Chief Materials Engineer.
- During his spell with the CPA he was intimately involved in the design, manufacture and construction of asphalt as well as formulating standard specifications and quality assurance procedures.
- Served as Executive Director of Sabita.

Among these specialists they have experience as clients, contractors, suppliers and consultants. 5 of them are currently employed as consulting engineers. 3 are currently employed as asphalt suppliers. 2 of them were employed by provincial authorities. All of the specialist have experience as contractors.

The following section discusses the goals of the interview and the formulation of the question list.

3.5 Interview Formulation

The interviews were conducted with specific goals in mind. The questions that were asked thus had to achieve the goals that had been set. These goals are the following:

- To determine the current state and potential future growth of the use of these technologies in South Africa (number of projects, annual increase in technology use, etc.).
- To determine what the regional interest in these technologies are in South Africa.
- To identify the benefits of these technologies through the interviews to compare them to those ones already identified in Chapter 2.
- To identify potential risks caused by using these technologies, these risks would include contractual, design and construction risks.

<u>The questions:</u>

The following questions were asked during the interviews. The reason for the inclusion of each question is also given.

1. *What is your involvement in the asphalt industry? This includes your industry experience, committee memberships (example Sabita) and your involvement in these technologies.*
   - **To determine the practitioner's relevant experience.**
2. *How many projects that you know of are currently using these technologies in SA (RA and WMA)?*
   - **To determine the number of projects using these technologies and to get an indication of the current popularity of these technologies in South Africa.**
3. *What are your reasons for applying these technologies (RA and WMA)?*
   - **To determine what motivates the practitioner to use these technologies.**
4. *Provincial use of RA and WMA:*
   - **To determine what regional are involved in the development of these technologies and who does not show any interest.**
     a. *Which SA provinces that you know of are currently using these technologies (RA and WMA)?*
     b. *Which provinces that you know of are interested in using these technologies (RA and WMA)?*
     c. *Which provinces that you know of do not show any interest in using these technologies (RA and WMA)?*
5. *What have you found to be the advantages of using these technologies (RA and WMA)?*
   - **To determine the advantages that can be compared to the advantages taken from literature in Chapter 2.**
6. *Please list as many as possible risks involved in applying these technologies in the following phases (RA and WMA):*
   - **To identify the risks involved in applying these technologies in the following phases.**
     a. *Design phase:*
     b. *Production phase:*
     c. *Construction phase:*
7. *According to literature there is an increase in the use of these technologies in SA, can you indicate how much this increase is? Possible indicators: Annual asphalt production, increased testing, more trials (RA and WMA)?*

- **To determine the increase value of these technologies to investigate the future of this technology in South Africa.**

8. *According to your opinion is this increase going to continue?*
   - **To determine the continuity of this technology in South Africa.**
     a. *If so, why?*
     b. *By how much?*
9. *Have you encountered problems with the application of these technologies that would stop you from using it?*
     a. *If so, what problems?*
   - **To identify problems that is severe enough to stop the practitioner from using these technologies.**
10. *Can you please list consulting engineering firms that are currently implementing these technologies (as I would like to collect as much information as possible):*
   - **To expand the expert list to enable a wider variety of opinions.**

3.6 Interview Discussions

This section discusses the information procured from the interviews under the following headings.

3.6.1 Use of These Technologies in South Africa

This section discusses the feedback that was received on Question 2, Question 7 and Question 8 of the interview. These questions focus on the current use of these technologies in South Africa as well as the predicted future use of these technologies.

Current use of these technologies:

According to the specialists RA technology (up to 40% RA) is used fairly extensively in South Africa and the South African National Roads Agency Ltd. (Sanral) is seen as the driving force behind the use of RA. However according to Pieter Myburgh almost all asphalt is produced by using RA of percentages up to 10% (Myburgh, 2013). These low percentages are however not always declared as RA.

WMA technology is considered by the specialists to be used less extensively and at the moment it is only being continuously supported by the eThekwini Municipality (Durban). The specialists were asked how many projects they are aware of at the moment that uses WMA technology. Most of the specialists knew of only 2 projects that use WMA at the moment. However according to Wynand Nortjè there are 3 more projects that are about to commence that uses WMA technology (Nortjè, 2013). According to Deon Pagel (2013) from National Asphalt they are shortly going to produce only WMA from their Durban based Cliffdale plant (foamed WMA technology) unless HMA is specifically requested by the client (Pagel, 2013). According to Herman Marais from Much Asphalt they are producing WMA at a regular basis at 2 of their plants and on an ad hoc basis in their other plants (Marais, 2013). National Asphalt and Much Asphalt are the two largest asphalt suppliers in South Africa who contribute 80% of South Africa's asphalt combined (Pretorius, 2013) (Also available in Appendix D). According to Pagel (2013) two of the 40% RA projects he is aware of use WMA technology as well (Pagel, 2013).

The current use of RA technology is used more extensively than WMA technology. RA is driven by Sanral who is the largest road authority in South Africa. This technology will thus be introduced into more projects. The use of WMA technology also shows good signs for growth as the asphalt suppliers are introducing this technology permanently to some of their plants. The combined use of these technologies can potentially improve the benefits to the asphalt industry. This can also increase the use of WMA technology as the realisation of the combined benefit with RA technology may increase the specification of this technology.

Future use of these technologies:

According to the specialists there will be a gradual but steady increase in the use of these technologies as the potential benefits are large enough not to ignore. According to them there are numerous factors that affect the increase in growth of both these technologies. These factors are discussed below.

Firstly looking at RA technology the following table (Table 10) shows the factors that affect the growth of this technology. Table 10 also indicates if the factor will have a positive or a negative effect on the growth of this technology in South Africa.

	Table 10: Factors that influence the growth of RA technology	**Effect on the Growth**
1	Increase in the realisation of the economic (reuse of old bitumen and aggregate) and environmental (recycling) benefits.	Positive
2	South Africa uses thin asphalt layers which limits the available amount of RA. The use of RA can thus increase but will even out as the RA limit is reached.	Negative
3	The use of RA will increase fast as it is driven by asphalt suppliers. Asphalt suppliers realises the economic benefits of this technology and is thus interested in increasing RA use.	Positive
4	The use of RA will increase as it has the support from large road authorities (Sanral and eThekwini Municipality) and the idea of RA has been planted in South Africa for more than 20 years.	Positive

Factors 1, 2 and 3 will cause this technology to increase. However, factor 2 will have a significant effect on the growth of this technology as this will limit the amount of RA that is available and with the increasing RA content in asphalt mixes it will limit the amount of projects that can specify this technology. The growth will thus increase until most of old pavements have been recycled and will thus have a positive impact on the environment.

Secondly looking at WMA technology the following table (Table 11) shows the factors that affect the growth of this technology. Table 11 also shows if the factor will have a positive or a negative effect on the growth of this technology in South Africa.

	Table 11: Factors that influence the growth of RA technology	**Effect on the Growth**
1	Increase in the realisation of the economic and especially the environmental benefits.	Positive
2	As soon as WMA's performance properties can thoroughly be proven and recorded to be the same as HMA it can replace HMA in project specifications and increase the use of the technology.	Negative
3	Any HMA can be manufactured as a WMA. The technology is thus not limited to specific mixes.	Positive
4	Global pressure of technology development and green engineering can provide motivation for an increased use.	Positive
5	The increase in carbon taxes provides a financial incentive for asphalt manufacturers to invest in this technology.	Positive
6	The growth may be slow as the technology is fairly new to South Africa and the necessary knowledge to specify this technology in projects is lacking from many engineers and clients.	Negative

The growth of this technology will increase as factors 1, 3, 4 and 5 cannot be ignored. This growth will however be slow as factors 2 and 6 can take a while to be overcome. This technology is however not limited and can be used in any HMA mix. This technology thus has the potential to replace HMA completely.

3.6.2 Regional Interest

According to the specialists the following provinces are starting to realise the benefits of the RA and WMA technology.

- Kwazulu-Natal Department of Transport,
- Gauteng Department of Roads and Transport.

There are currently RA and WMA projects on going in these provinces which clearly show their interest in these technologies. According to the experts the eThekwini Municipality (Durban) consistently promotes both technologies as a municipal body. There are RA and WMA projects on going in the Free State but these are however endorsed by Sanral and not the Free State

Department of Transport. The Western Cape is also showing interest in these technologies but the technology has not been specified in projects in this province. The provinces that currently show no interest in these technologies according to the information procured are thus the following.

- Limpopo Province,
- North West Province,
- Northern Cape,
- Eastern Cape,
- Free State.

According to Pieter Myburgh (2013) the lack of interest can be contributed to the diminishing of professional resources (engineers that can initiate and manage the use of RA and WMA technology) in these provinces and thus not being capable of policy formulation with respect to these technologies (Myburgh, 2013).

3.6.3 Technology Benefits

The specialists were asked to list the main benefits of these technologies. The main reason for this question was to compare the benefits according to the specialists with the benefits identified in Chapter 2. In Chapter 2 the reduction of the environmental impact and the cost savings were identified as the main benefits of these technologies. All 9 of the experts stated that the main benefits of these technologies are the environmental impact reduction and the cost savings. The correlation between the study done in Chapter 2 and the specialist interviews confirms that an environmental analysis and a cost analysis needs to be done in this study to investigate the magnitude of these benefits.

3.6.4 Technology Risk Identification

The specialists were asked to discuss the risks involved in using RA and WMA technology in the following phases:

- Design phase: This phase includes the design of the asphalt pavement.
- Production phase: This phase includes the production of the asphalt.
- Construction phase: This phase includes the construction (laying and compaction) of the asphalt pavement.

The following sections list and discuss the risks that were identified through the interviews with the specialists.

<u>WMA Technology:</u>

Table 12 lists and describes the identified risks that the use of WMA technology may have on the South African asphalt industry. These risks are discussed in the following paragraphs:

Table 12: WMA Technology Risks

Design Risks	**1**	Establishing the optimal technology among a number of options that would be conducive to the plant, site location and construction capability of the laying contractor. There are in excess of 20 different WMA technologies on the market with each product having its own advantages and limitations so it would be very difficult to specify WMA.
	2	Not presently specified in COLTO, so new WMA project specifications have to be drawn up.
Production Risks	**1**	The use of WMA technology is not specified in COLTO. The WMA technology dosages are sometimes still adjusted during the production phase (as a result of initial design faults) which has time and cost related risks.
	2	The plant must be able to run at lower temperature settings (up to 30°C) and if even temperature distribution in the drum at the lower temperature cannot be achieved then aggregate coating problems can arise.
	3	If the WMA technology is not properly implemented/added/mixed during production it could cause poor quality performance.
Construction Risks	**1**	WMA brings about a much larger compaction window and this can result in over compaction. WMA can be compacted at a lower temperature than HMA (as a result of the WMA additive). If WMA is compacted at the same temperature as HMA it compacts faster and may lead to over compaction.

- **Design Phase:**

According to the specialists the main risk in the design phase of using WMA technology is that it is difficult to select an appropriate technology as there are many different types of WMA technology as discussed in Section 2.3. This risk is aggravated by the fact that WMA technology is not specified in the Standard Specifications for Road and Bridge Works for State Authorities published by and also referred to as COLTO (Committee of Land Transport Officials) (Committee of Land Transport Officials (COLTO), 1998). Consulting engineers must thus use other sources of knowledge (researchers, help from abroad, other companies, etc.) to design a WMA pavement. They must thus design a pavement structure without any specifications, never mind the risk of selecting the appropriate technology. New specifications must thus be drawn up for every WMA project. The design risk is thus carried by the client as well as the consulting engineer. This risk can lead to premature failure of the pavement (as no performance specifications are available), cost overruns, time losses as well as a possible loss of their company's reputation. The design risks are thus attributed to no specifications and a lack of knowledge and experience with this technology.

- **Production Phase:**

Another risk as a result of the lack of WMA specifications in COLTO is that wrong initial mix design can result in redesign during the production phase. This redesign or rectifying of mix quantities (WMA additive quantities, binder quantities, etc.) causes time and cost overruns as the production process is stopped. The risk can be aggravated by not realising the faulty mix during production which can lead to the construction of this mix and finally to premature failure of the asphalt pavement during its service life. Another cause of risk is to ensure that the plant can heat the mixing drum at a constant lower temperature. Too low temperatures lead to aggregate coating problems. If the aggregate is not coated properly moisture can reach the aggregate and cause adhesive problems between the aggregate and binder. The coating problems cause clean spots on the aggregate that can be seen with the naked eye. This leads to rejection of asphalt mixes and causes cost and time overruns because of reproduction.

- ***Construction Phase:***

According to the specialists there is not too much risk involved in the construction of a WMA mix. The main risk is actually caused by one of WMA technology's advantages, the longer compaction window. Construction teams are used to compact HMA to a certain specification. They thus tend to over compact WMA as it is compacted easier than conventional HMA. Over compaction can lead to possible premature aging of the pavement as well as a pavement with reduced flexibility that can cause cracks under heavy traffic. According to the specialists this risk can easily be eradicated by ensuring proper density control during the compaction process.

RA Technology:

Table 13 lists and describes the identified risks that the use of RA technology may have on the South African asphalt industry. These risks are discussed in the following paragraphs:

Table 13: RA Technology Risks		
Design Risks	1	If the client specifies a minimum RA percentage it puts a limit on the number of contractors that can bid on the project as there are limited asphalt plants in the country that can use more than 25% RA successfully.
	2	It needs to be understood by Client bodies and designers (engineers) that the higher the RA content that is specified, the more the RA need to be processed before use (More crushing and screening into different fractions).
	3	Lack of maintenance and control of the RA stockpiles.
	4	Making a realistic, stochastic analysis of the RA in stockpiles in terms of composition, moisture and binder qualities (where appropriate i.e. where higher RA content is contemplated). To determine optimum RA percentage in new mix.
	5	Not presently specified in COLTO, so new project specs have to be drawn up
	6	The specifying of RA on high risk projects with very high traffic needs to be considered with care. If the RA is not treated correctly premature failures could occur.
Production Risks	1	RA introduction into the drum must be well managed in order to prevent burning of the RA’s residue binder or further ageing of the binder.
	2	Fluctuation in binder content as a result of the high RA content (that contains residue binder).
	3	A lack of quality control: The particle size of the RA, the properties of the residue binder and foreign matter in the RA must be monitored as it is relevant to the quality of the asphalt mix.
	4	Using the correct amount of softer binder or rejuvenators in high RA content asphalt mixes to maintain a manageable workability.
	5	Lack of proper RA stockpile control that ensures that the different particle sizes are kept separate and dry.
	6	To low temperatures can lead to partial coating of the aggregate and moisture being trapped and then cause adhesion problems.
	7	Mixing plant capabilities. Incorrect production plant and systems.
Construction risks	1	In the normal sense RA poses no risk on the construction side but if a high RA contents is used in conjunction with a rejuvenator then it will become a WMA technology which then can result in over compaction if the contractor is not familiar with the procedure.
	2	High RA content mixes may contain some moisture of the RA (although below COLTO maximum of 0.5%) that can cause the mix to be tender.

- ***Design Phase:***

According to the specialists there are not many plants in South Africa that can produce asphalt with a RA percentage of above 25%. When the client specifies a minimum RA content it must be realised that there are only a few plants capable of producing these mixes and the number of suppliers are thus limited. This can cause procurement problems which can lead to cost overruns.

Another risk identified by the specialists is that the client or engineer doesn’t realise that the higher the RA content they specify, the more processing is involved in obtaining the right grade of RA. As more RA is specified the RA gradation must fit into the grading envelope (discussed in Appendix B).

The RA must thus be processed into more sizes to allow it to fit the grading envelope. Another risk that arises from the specification of high RA percentages is the fact that not all RA can be processed into small sizes to fit the mix gradation. The result is that the client or engineer specifies a minimum RA content which cannot be met with the RA that is available for that project. The RA that is going to be used for a project must thus be analysed to investigate the possible grading sizes that can be procured from that specific RA batch and thus to determine the optimal RA content that can be specified.

Another risk is that there are no specifications of RA in COLTO and new specifications must thus be drawn up for each project. This can also lead to initial faulty designs (such as wrong minimum RA content specifications) which must be adjusted during the production process that may cause time and cost overruns.

RA technologies practitioners (engineers, researchers, clients, suppliers and contractors) are still investigating the effect that high RA content mixes have on the long term performance of roads that receive heavy traffic loads. It is thus still considered a risk to specify high RA content mixes to roads that undergo heavy traffic loads.

- ***Production Phase:***

Plants that are used to mix high RA content asphalt mixes must be modified in order to correctly introduce the RA to the mixing process. The mixing drum and the burner must be configured in a way that the RA does not come in contact with the burner but still be heated to a proper mixing temperature (also to allow moisture evaporation). If the RA comes in contact with the burner flame it causes large amount of smoke (bitumen fumes) that is harmful for the workers on the site. The direct burning of the RA also causes premature ageing of the residue binder in the RA which reduces the binder’s long term durability and can cause quality problems in the mix.

A lack of quality control of the RA processing and stockpiling can lead to a number of risks. After the RA has been processed into different sizes it must be monitored to ensure that there are no foreign matters in the RA that may be harmful to the plant. The residue binder content in the RA must also be monitored and analysed on a regular basis to determine the amount of virgin binder that needs to be added to the asphalt mix. The properties of this residue binder must also be monitored and analysed to ensure that the right type of virgin binder (with the appropriate properties) is applied in the plant as the residue and virgin binders must combine to form the design binder specifications.

Premature pavement failure and workability problems during construction can arise if proper quality control measures are not applied during the RA processing and fractioning.

RA must be kept dry during stockpiling as it can cause moisture problems during the mixing process. To low mixing temperatures may cause partial moisture evaporation that causes moisture to remain on the RA aggregate which causes adhesion problems with the binder. Moisture control and monitoring is thus crucial to eliminate coating and adhesion problems.

Another risk that can occur by producing high RA content asphalt mixes is the application of the rejuvenator that rejuvenates the old residue binder (as described in Section 2.3). The rejuvenator content must be monitored and adjusted if necessary to ensure an appropriate workability level of the asphalt mix.

- ***Construction Phase:***

RA does not pose too much risk to the construction phase. The main risk arises when the rejuvenator that is used in the production process is also a WMA technology. High RA content mixes is rejuvenated with an agent that can sometimes make it a WMA mix which may cause over compaction as discussed in the WMA risk section.

3.7 Conclusion

Use in South Africa:

RA has been used in South Africa since the 1980's and this allowed authorities to become used to the idea of the technology. The implementing of higher percentages of RA mixes (up to 40%) is thus easily integrated into the South African industry. Sanral who is the largest road authority in South Africa is the driving force of RA technology and thus integrates it into many projects. WMA technology is currently not used extensively. There is however clear signs that the technology can be used successfully in South Africa. The two largest asphalt suppliers as mentioned before have invested in the manufacturing of WMA. There is also an increase in the number of projects that use WMA technology. The combined use of RA and WMA technology also appears to be a trend that is being adopted by asphalt manufacturers.

It was found that the integration of these technologies in the South African industry shows an increase. Factors that influence the growth tempo of these technologies was identified from the specialists' interviews (see Table 10 and 11).

It was found that RA will show a faster initial increase than WMA technology as this technology has been known to the South African industry since the 1980's and is driven by large road authorities such as Sanral. It has also been found that practitioners are realising the economic and environmental benefits of these technologies which will increase the use of these technology. As South Africa mainly uses thin asphalt layers the amount of RA is however limited and the increase in the use of this technology will even out as soon as the RA is fully utilized. The use of WMA technology is however not limited as it can replace any HMA as it is not limited to certain materials. WMA technology is however a new technology to South Africa (since 2008) and is not yet driven by large authorities as in the case of RA technology. There are still some quality issues that put doubt in authorities' and other practitioners' minds for the use of these technologies. Other factors such as the international pressure to promote green engineering and the increasing carbon taxation were also identified as further motivation to integrate these technologies into the industry.

The following road authorities were identified by the specialists as the authorities that are currently showing support for the use of these technologies:

- Kwazulu-Natal Department of Transport (Provincial),
- Gauteng Department of Roads and Transport (Provincial),
- eThekwini Municipality (Municipal),
- Sanral (National).

According to the data procured from the specialists the following provinces do not currently show interest in these technologies: Limpopo Province, Free State, Northern Cape, Eastern Cape and North West Province.

There are thus road authorities that are realising the benefits of these technologies. It is however found from the feedback that five of the nine provinces in South Africa do not currently show interest in these technologies from a lack of knowledge and professional resources. It is thus important that Sanral is starting to endorse these technologies as they are a country wide authority and serves as the client in major projects around the country (including the five non-interested provinces). These are however only a small number of authorities and the technology integration process can be considered as slow.

<u>Technology Risk:</u>

After interviewing the specialists the main risks that RA and WMA technology holds for the South African Asphalt industry were identified. These risks were grouped into three phases, namely: design phase, production phase and the construction phase. The identified RA and WMA technology risks are listed and described in Table 12 and Table 13 separately. The most important reasons for these risks are discussed below.

- ***Design Phase:***

The main cause of risk in the design phase is that there are currently no specifications for the use of RA or WMA technology in the COLTO design manual which is the primary design manual that is used during road design in South Africa. There are over 20 different WMA technologies (of which each have different limits and advantages) available in South Africa which makes the risk of designing a WMA mix without standard specifications very difficult and risky. One of the main reason for risk during the design phase of a high RA content mix (above 25%) is that designers do not include the variable properties of the RA's residual binder or aggregate sizes into their design parameters. A minimum RA content can thus only be specified after the RA's properties have been analysed as it is sometimes impossible to match the high specified RA content's properties with the mix designed for the project (example: to meet the specified grading of the mix or to achieve the desired binder content and viscosity through the blend of virgin binder and residual binder). Combining these reasons with a lack of experience and understanding of both these technologies can cause more risk to a project.

- ***Production Phase:***

The reasons for risks arising in the production phase of WMA is the lack of standard specifications for this technology which leads to WMA technology dosages being adjusted during the production phase which has an effect on the asphalt quality, cost and time of the project. The plant's capabilities are also one of the main reasons for the occurrence of risks in the production phase. WMA requires certain functions such as to maintain a constant temperature (which is much lower (up to 30°C) than the conventional temperature of the plant) to properly mix a WMA mix. RA also requires certain capabilities by the plant to produce a proper RA mix. These capabilities include: Managing the introduction of the RA into the mixing drum to avoid contact with the burner flame, to heat the RA to ensure the evaporation of most of its moisture. Quality control and monitoring of the RA stockpiles are one of the main reasons for risks arising in the production process. The stockpiles must be kept dry and the particle sizes must be monitored. The residual binder content in the RA as well as the residual binder's properties must be monitored throughout the production process as these factors have a direct effect on the quality of the final asphalt mix.

- ***Construction Phase:***

The construction phase was identified as the phase that holds the least amount of risk for a project that uses RA and WMA technologies. The only risk that was identified was caused by one of the benefits of WMA technology. Over compaction of the asphalt layer may occur as a result of the larger compaction window. This can however be easily eradicated by carefully monitoring the layer density during the compaction process.

The insufficient training and work experience along with a lack of specification and a lack of guidelines for the use of RA and WMA technologies are therefore the main reasons for the risks on these technologies.

Next Chapter:

An environmental and cost analysis will be done in Chapter 5 and Chapter 6. Chapter 4 describes the strategy that is going to be used to conduct an environmental and cost analysis to investigate the magnitude of these technologies. The specialists also stated that there is a tendency in South Africa to combine the RA and WMA technology. The analyses are thus going to be conducted on a combination of these technologies.

CHAPTER 4: TECHNOLOGY IMPACT QUANTIFYING STRATEGY

4.1 Introduction

Chapter 4 discusses the strategy that is followed to analyse these impacts. This chapter describes the life cycle analysis (LCA) that is used to analyse the environmental impact. It also describes the life cycle cost analysis (LCCA) that is used to analyse the cost impact of the technologies on conventional HMA. The layout of the technology impact quantifying strategy is provided. This includes a description of the case study that is used as well as a definition of the boundaries that are set for the LCA and the LCCA. As the analyses are done on a case study, measures are also discussed that ensure the quality of the results. This includes verification of the data collected as well as sensitivity analyses where needed. The limitations of the analyses are also discussed.

The aims of this chapter are:

- To define the methods used to analyse the environmental and cost impact.
- To provide a layout to describe the strategy that is followed.
- To select and describe the case study that is used in the analysis.
- To properly define the boundaries as well as the limitations of the analyses.
- To set sufficient measures to ensure the quality of the results.

4.2 Quantification Methods

As described in the introduction of this chapter, a LCA and a LCCA will be performed to quantify the environmental and cost impacts of the application of the technologies. These analyses are described below:

- **Life Cycle Analysis (LCA):**

The impact of a production process on the environment is often difficult to quantify because of the wide spread environmental components thereof. It is thus useful to implement a life cycle approach where all the different components of a product are considered and evaluated. The main components normally include the procurement of the raw materials, the transportation of the raw materials as well as the transportation of the product to where it will be applied and the different processes such as manufacturing. These components are evaluated through their energy usage as well as through the amount of emissions produced. The purpose of a Life Cycle Assessment (LCA) is to document environmental considerations and to help making decisions based on sustainability. LCA stretches from the raw material procurement through to the disposal of the manufactured product after it has been used. (Babu, 2006)

The quantification of environmental impact can be done by means of two methods: Carbon footprint as well as energy efficiency.

Carbon footprint is defined as the carbon dioxide (CO_2) emissions that are released by a certain entity. These emissions are caused by the combustion of fossil fuels. In this study the entity is the asphalt life cycle. The carbon footprint of an entity is thus the specific impact of the entity on the environment. (Wiedmann & Minx, 2007)

Energy efficiency is simply defined as doing the same work but using less energy. Energy consumption is measured in MJ/ton. This unit indicates the amount of energy used to produce one ton of the product. (Collings & Jenkins, 2009)

In this analysis the energy efficiency of the RA and WMA technology will be determined by comparing it to a conventional HMA (that does not implement these technologies). Energy efficiency is used as the quantifying method as it does not only include fossil fuels but all other sources of energy as well (Statistics South Africa, 2005).

The analysis is based on the ISO 14040 (International Organization for Standardization, 1997) document which provides extensive guidelines to conduct a LCA.

- **Life Cycle Cost Analysis (LCCA):**

The LCCA is a systematic approach to quantify and compare the economic impact of a project. There are four important steps to completing a LCCA. These are the collection of data, the identification of important components, the calculating of cost demands as well as the incorporation of possible cost reduction methods (Babu, 2006).

LCCA is widely used as a tool to assist road authorities to select the most cost effective construction, production, and maintenance or rehabilitation option (Hicks & Epps, 2000).

The LCCA conducted in this study is done on the same scope as the LCA. Additional costs of using the technologies are also included. The analysis is also based on the ISO 14040 document (International Organization for Standardization, 1997).

The LCCA compares the cost effectiveness of conventional HMA with the integration of the RA and WMA technologies.

4.3 Strategy Layout

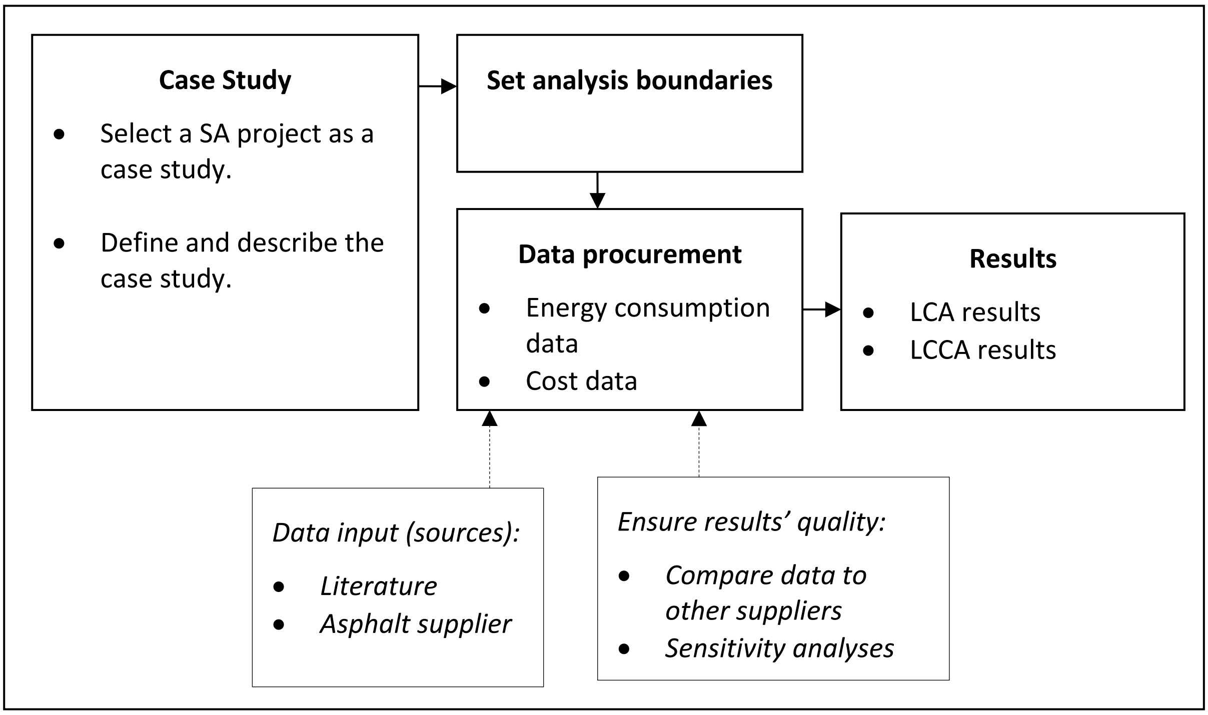

Figure 6: Experimental Layout

Figure 6 shows the graphical illustration of the experimental considerations. It was decided to select a case study of a current project in South Africa. This project must incorporate the RA and WMA technologies to allow a proper analysis to be done. The analysis boundaries must be defined to clarify what areas of the HMA life cycle are included. The data for the analyses are collected from the project participants themselves to ensure the quality of the data. For those areas where data is not available, literature will be used to fill the data gaps. To ensure the quality of the results of the LCA and the LCCA, sensitivity analyses are done on parameters where variance may influence the final results (Example: transportation). The data parameters that have the largest influence on the results are also identified and then confirmed by consulting other suppliers. This ensures results that can be used to identify the risks and benefits of the technologies, in a reliable and unbiased manner.

4.4 Case Study

The case study is a project that is currently ongoing in South Africa and which is relevant for this seeing that RA and WMA technologies are used on the project. The South African National Roads Agency Limited (Sanral) acts as the client for this project. The project name is shown below:

- Periodic Maintenance of National Route 1, Section 18 between Kroonvaal toll plaza (km 68.2) and Vaal River (km 78.2). The length of the project is 10 km.

Figure 7: N1 Site Location

Figure 7 shows the location of the project. The asphalt plant is situated 10km north of where the project starts. The following information was obtained from the contract document for the project compiled by V&V Consulting Engineers (V&V Consulting Engineers, 2012).

- There are 2 lanes in both directions (north and south). The case study is based on the south bound slow lane (thus the outside lane) between km 69.4 – km 78.2. The width of the lane is 3.7m. The existing pavement and new pavement structures are described in Table 14.

Table 14: Pavement Structure

Old Pavement Structure			Maintenance plan	New Pavement Structure	
Maintenance history	3rd resurface (2004)	UTFC (18mm)	Mill out	Resurface	UTFC (18mm)
	2nd resurface (1994)	40 AC		Base	**BTB (85mm)**
	1st resurface (1988)	40 AG			
Pavement composition of original construction in 1977	Base	90 BS	Leave as it is	Base	90 BS
	Upper sub base	150 C3		Upper sub base	150 C3
	Lower sub base	150 C3		Lower sub base	150 C3
	Selected	125 G7		Selected	125 G7

- As seen in Table 14 the surface layers are milled out (milling depth is 100mm) and replaced with a bituminous treated base (BTB) of 85mm and covered with a surface layer of ultra-thin friction coarse (UTFC).
- The BTB layer highlighted in Table 14 is the asphalt layer that will be used in the case study. This layer is a WMA layer that includes a RA percentage of 40% (as prescribed by the client, Sanral).

- The BTB is a continuously graded mix with a maximum sieve size of 26.5mm.
- The WMA technology that is used on this project and that will be analysed is an organic additive called Sasowax 1655. The volume of WMA additive needed is 0.7% of the total bitumen volume.
- The binder specified for the BTB layer is an 80/100 bitumen that is modified with AP-1 (in this case a 5% EVA modifier). A binder content of 4% is specified for this project and a filler (lime) content of 1%.
- The annual daily E80's (ADE) in the north direction (recorded in 2011) is 1659 and in the south direction (recorded in 2011) 1673. The road is designed for a period of 15 years.
- A Drum mixing plant will be used.
- The mixing plant is situated in Vanderbijlpark and has a mixing capacity of 100 ton/hour.
- As the case study is based on the 85mm BTB layer, the asphalt volume that will be used in the analyses can be determined. The project length is 10km and the minimum compaction density of the BTB must be 2341kg/m^3. The asphalt tonnage is thus calculated to be 7362.45 tons. The quantities of each material are shown in Table 15.
- The residual bitumen obtained from the RA contributes 1.8% to the binder content. The amount of virgin bitumen added is thus 2.2%.

Table 15: Material Quantities

Material	Mix content (%)	Tonnage
Bitumen	4.00%	294.50
Aggregate	95.00%	6994.32
Lime	1.00%	73.62
Total	100.00%	7362.45
WMA additive	0.7% of Bitumen	2.06

4.5 Scope of analysis

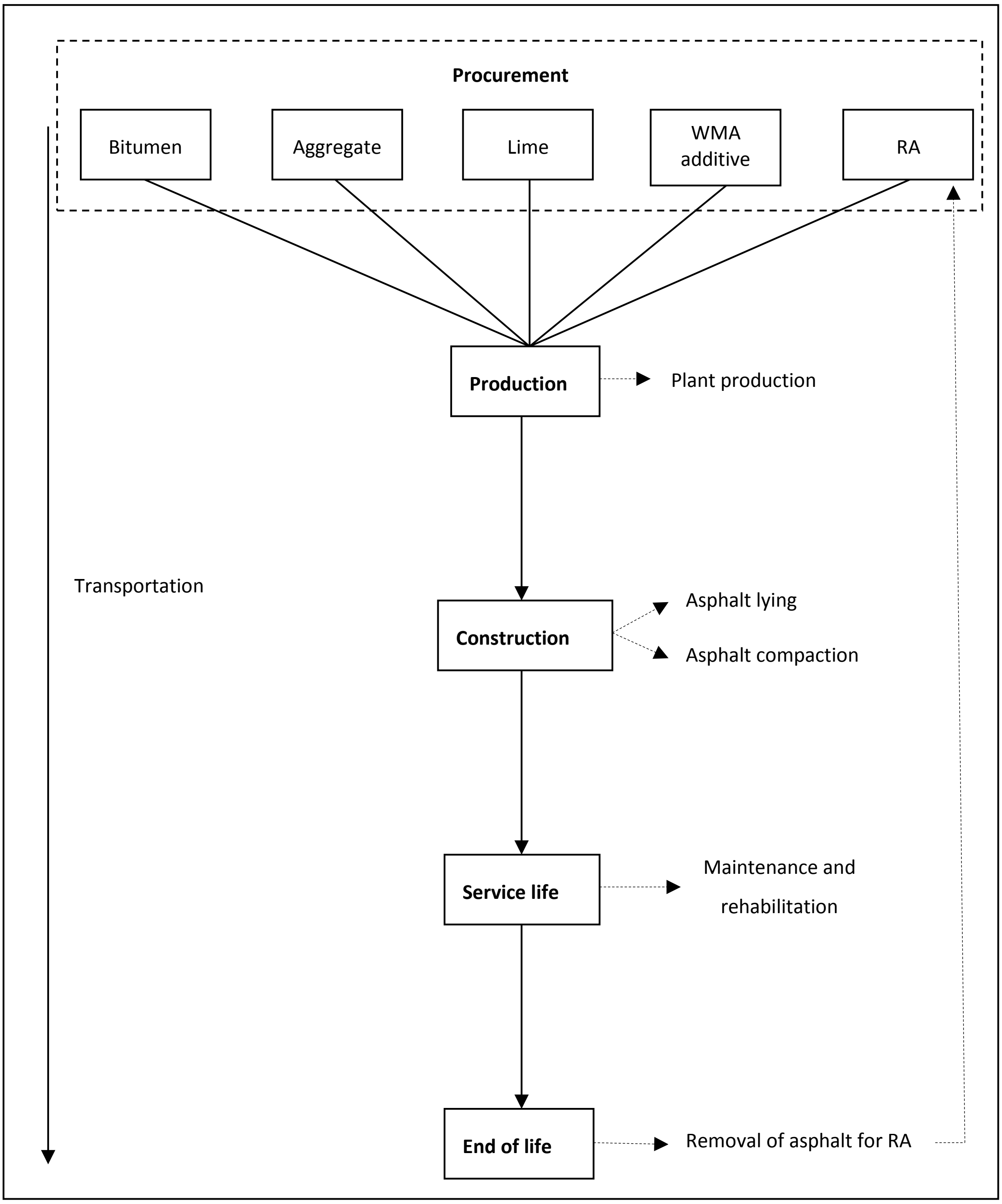

Figure 8: Analyses Boundaries

Figure 8 shows the boundaries that are selected for the analyses. The boundaries are categorised into five parts:

- Procurement: Includes the procurement of bitumen, lime, aggregate, WMA additive and RA (which is obtained from the end of life phase as shown in Figure 8).
- Production: Includes the asphalt production in the plant.

- Construction: Includes the asphalt laying and compaction.
- Service life: Includes the maintenance and rehabilitation of the asphalt.
- Transportation: Includes the transportation through the whole production and construction process (the solid arrows in Figure 8).

4.6 Mix Models Definition

In Chapter 2 the benefits of RA and WMA were identified and listed. To investigate these benefits it is important to select asphalt mix models (that will be analysed) in such a way that the benefits are emphasised and incorporated in the analysis. The different variations of the technology usage must thus be covered. From the results in Chapter 2 it is concluded that the following are the main variables as a result of the technologies usage:

- Addition of the WMA additive to the production process.
- Reduction in the use of aggregate because of the RA use.
- Reduction in the use of bitumen because of the RA use.
- Lower temperature in the production process through the use of WMA technology.
- Less compaction effort required in the asphalt compaction process through the use of WMA technology.
- Possible variation in service life of the asphalt.

These variables have possible effects on both the cost and environmental impact of the asphalt.

According to an analysis done by Zaumanis (2010) in Denmark a method of percentage allocation according to variables were used to define different mix models (Zaumanis, 2010). The study allocated a percentage of 100% to a reference HMA mix (that does not use any one of the technologies). The study then varied different HMA and WMA mixes and allocated different percentages to different processes. This method is applied to this study. Table 16 shows the four mix models that are selected for the analyses. They include varying amounts of RA as well as varying use of WMA technology.

Mix model one is selected as a reference mix. The second mix model is selected to investigate the effect of only the WMA technology on the HMA. Mix model three is selected as an option that can most likely be implemented in South Africa. As South Africa is known for using thin asphalt layers it is assumed that the amount of RA is limited and thus uses a RA content of 20% (rather than 40%). The selection of 20% is also assumed to be more practical as not many plants can produce 40% RA mixes in South Africa. Mix model 4 is selected to investigate the potential effect of both the WMA and RA technologies to the maximum extent in South Africa (thus 40% RA and WMA technology).

	Table 16: Mix Model					
		WMA additive (% of bitumen content)	**Energy use of plant**	**Energy use on Compaction effort**	**Aggregate savings**	**Bitumen savings**
1	**HMA, reference**	0.00%	100.00%	100.00%	0.00%	0.00%
2	**HMA with 20% RA**	0.00%	110.00%	110.00%	20.00%	22.50%
3	**WMA with 0% RA**	0.70%	80.00%	80.00%	0.00%	0.00%
4	**WMA with 40% RA**	0.70%	80.00%	80.00%	40.00%	45.00%

The composition of the asphalt mixes are thus adjusted to show the effect of these variables. The following comments are made about Table 16.

- The HMA with 20% RA uses more energy to produce and to compact, as the combination of virgin binder and residue binder (from the RA) makes the binder very stiff as the residue binder is stiff as a result of aging and needs to be processed at a higher temperature. The normal mixing temperature for HMA can be considered to be between 165°C and 175°C and with a 20% RA content the temperature can increase to 195°C. On average the energy increase in the mixing process (dependent on the type of mixing plant) can be taken as 10%. (Nortjè, 2013)
- The WMA mixes are mixed at a lower temperature (around 145°C) which gives an energy reduction of 20% (Zaumanis, 2010).
- These energy reductions are also relevant to the compaction process (Lewis et al., 2011).
- The aggregate and bitumen savings are directly subtracted from the original procurement amounts (Zaumanis, 2010). According to National Asphalt (Stander, 2013), 1.8% of the binder content (N1 project binder content specification is 4%) is made up of the residual bitumen obtained from the RA (when 40% RA is used), which is thus a bitumen saving of 45%. The bitumen savings on each project (that uses RA and WMA technology) vary as it is dependent on the RA content used as well as what the required binder content is for the specific project (Nortjè, 2013).

4.7 Results Quality Assurance

The data that is required for the analyses was obtained through correspondence with the asphalt supplier, National Asphalt, as they are the company responsible for the most of the processes that are being analysed. Some of the components of the analyses are project specific that may have an effect on the results. A sensitivity analysis will thus be done on certain components that are project specific and that can have a significant effect on the results.

Input verification:

Through the course of the analysis the critical components are identified that have the largest effect on the results. These critical components are verified by comparing them to other suppliers in South Africa or values obtained literature.

Sensitivity Analysis:

The components for a sensitivity analysis will be identified through the course of the analyses. The sensitivity analyses are done to investigate and illustrate the effect that the variance of some components may have on the final results.

4.8 Limitations

The following limitations are identified for the LCA and LCCA that are conducted in this study:

- The case study is based on one project. The reason for this is that there is very little projects in South Africa that use both of these technologies on one project (especially RA up to 40%). As the use of these technologies varies with the change in project specifications, it was decided to use one project and cover the analyses very extensively.
- The analysis is done on a specific asphalt mix. The study is thus limited to a BTB mix (continuously graded).
- The WMA technology is limited to one which is the Sasowax 1655 (organic additive).
- The analysis is limited to a single binder (80/100 AP-1).
- Only the primary energy sources are analysed in the five HMA life cycle phases that are defined in the scope in Section 4.5.
- The data was procured from the asphalt supplier that supply for the N1 project. This data was however verified through sensitivity analyses and cross verification with other suppliers.
- The selection of the mix models is limited to four different models (these models however cover the different variations of the technologies usage).
- The LCA and LCCA focuses on the variable components which vary between conventional HMA and HMA that uses RA and WMA technology. Components that are considered to be constant for both the mix types are not included and focused on in the analyses, these include labour, equipment hire, premises hire, etc. The variable components are focused on as they are the

ones that will best show the effect of the technology integration. Figure 9 shows a graphical illustration of the variable and constant components. The white triangle represents the components that are considered in this study.

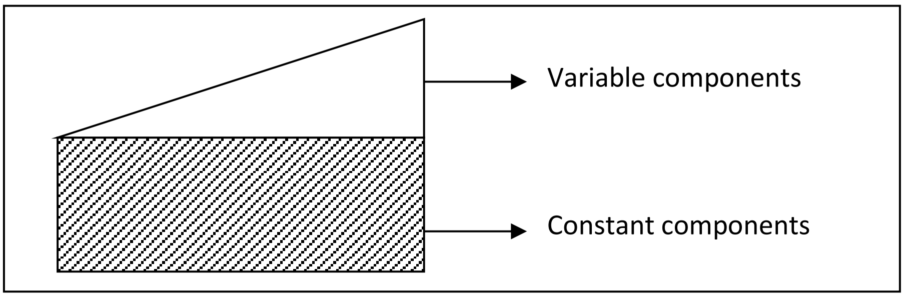

Figure 9: Component Focus

4.9 Conclusion

Chapter 4 provides a detailed description of the LCA and LCCA that are done in this study. The scope of the analyses is also defined as well as the limitations. The case study with a full description of the project is given. The quality assurance of the results is also discussed. The strategy that is followed in these analyses is clear and transparent and can be implemented.

The LCA is conducted in Chapter 5 and the LCCA is conducted in Chapter 6.

CHAPTER 5: ENVIRONMENTAL BENEFIT

5.1 Introduction

This chapter includes the energy consumptions of all the life cycle components of HMA as well as a discussion of the results obtained from the analysis. These components include: Material procurement, transportation, asphalt production, construction, service life and end of life. The chapter also includes the quality assurance of the results where sensitivity analyses are done on certain significant components.

The LCA incorporates the methods that were studied in the prior research (Section 2.4). The structure of the analysis is based on the study by (Zaumanis, 2010) but includes the service life of the HMA which is based on the study of (Jenkins & Collings, 2011). The application of this analysis on a case study was adopted from the study by (Cerea, 2010).

The aims of this chapter are:

- To procure sufficient input data from the N1 project as well as from literature where needed.
- To quantify the energy consumption of the four mix models defined in Chapter 4.
- To identify the most significant components of the life cycle on which quality assurance measures can be applied.
- To properly discuss the results and to identify the environmental benefits of the technologies as well as where (what components) these benefits are most apparent.

5.2 Data Procurement

The data and knowledge procurement for the LCA presented here was done by using the following methods:

- Data procured through literature.
- Data procured from the project itself, through communicating with the asphalt supplier as well as the main contractor on the site. The asphalt supplier is National Asphalt and the management members that were contacted are:
    - Chris Stander, a director of National Asphalt.
    - Wynand Nortjè, technical manager of National Asphalt.
- Data procured from the resident engineer (RE) on site, Mr. Jan Henning, V&V Consultants (Pty) Ltd.

The conversations were conducted through telephonic questioning as well as questioning via e-mails. The relevant e-mail correspondence is available in Appendix F and the e-mails are also referenced where necessary.

The following paragraphs provide the energy demands for all the components of the HMA life cycle defined in Chapter 4. These values may vary depending on the different conditions. The values in this study are based on South African data which was obtained through interaction with the industry (as shown in each case). In some cases international data was used because of a lack of local data. It is however important to notice that the possible variation in the data from the actual values in practice will be used for both the HMA and the WMA analyses.

5.3 Energy Consumption

The following sections calculate the energy consumptions of the HMA phases (analysis boundaries) that were defined in Chapter 4, namely: Material procurement, transportation, asphalt production, construction, service life and end of life.

5.3.1 Material Procurement

This section quantifies the energy consumption of the procurement of the asphalt production materials, namely: Aggregate, virgin bitumen, lime, RA and WMA technology additive. The energy consumptions provided in this section does not include the transportation of the material to the mixing plant. The energy consumption of the aggregate, bitumen and lime are obtained from international literature as no data is available in South Africa. An average of the international values is taken to determine the analysis values. It is important that the material energy consumptions include the same processes (Example: quarrying, blasting, etc.), to ensure a reliable average value. The energy consumption of the RA and WMA additive is calculated in a different way, which is discussed in their subsections.

Aggregate:

The following processes are included in the energy consumption (Stripple, 2001):

- Quarrying (rock blasting),
- Processing,
- Screening,
- Stockpiling at quarry.

The values differ as the studies were conducted by different researchers in different countries where different energy data is available. The variance is not that significant and no data is available in South Africa, an average value is thus considered as sufficient.

Table 17: Aggregate Procurement Energy Demand		
Region	**Energy demand (MJ/ton)**	**Source**
Sweden	38.50	(Stripple, 2001)
Europe	52.00	(European Asphalt Pavement Association (EAPA), 2007)
New Zealand	40.00	(Baird et al., 1997)
New Zealand	50.00	(Patrick & Moorthy, 2008)
Average	**45.13**	

<u>Virgin bitumen:</u>

The energy consumption includes the following processes (Eurobitume, 2011):

- Crude oil extraction,
- Transport to refinery (ship, road, pipeline),
- Complex refinery (includes production and storage).

These values vary from 3200 MJ/ton (Stripple, 2001) to 6000 MJ/ton (Häkkinen & Mäkelä, 1996). This large variation is attributed to the variance in the amount of crude oil imported as well as the shipping distances of the importation (Patrick & Moorthy, 2008). South Africa is heavily dependent on crude oil imports from the Middle East (Bergh, 2012). South Africa's crude oil is imported over a far distance and increases the shipping energy consumption. The energy consumption that was procured through literature varies between 3200 MJ/ton and 6000 MJ/ton. It has thus been decided to use the sources with the higher energy consumptions as they are more realistic in South Africa's situation (higher energy consumption).

Table 18: Bitumen Procurement Energy Demand		
Region	**Energy demand (MJ/ton)**	**Source**
Europe	4900.00	(Eurobitume, 2011)
New Zealand	6000.00	(Patrick & Moorthy, 2008)
Canada	5310.00	(ATHENA Sustainable Material Institute, 1999)
Finland	6000.00	(Häkkinen & Mäkelä, 1996)
Average	**5552.5**	

Lime:

These energy consumptions have a considerable variation. However, lime can be produced by different processes. The lime usage in the HMA mix is small and the variance in these consumptions thus has little to no effect on the results. An average value is thus accepted for this analysis.

Table 19: Lime Procurement Energy Demand

Region	Energy demand (MJ/ton)	Source
Europe	4000.00	(European Commission, 2001)
World Bank	4700.00	(World Bank Group, 2007)
USA	7200.00	(Miner & Upton, 2002)
New Zealand	7000.00	(Patrick & Moorthy, 2008)
Average	**5725.00**	

Reclaimed Asphalt (RA):

The energy consumption of the RA is divided into four processes (seen in Figure 10). According to Stander these are the main processes in procuring RA for the asphalt production process (Stander, 2013).

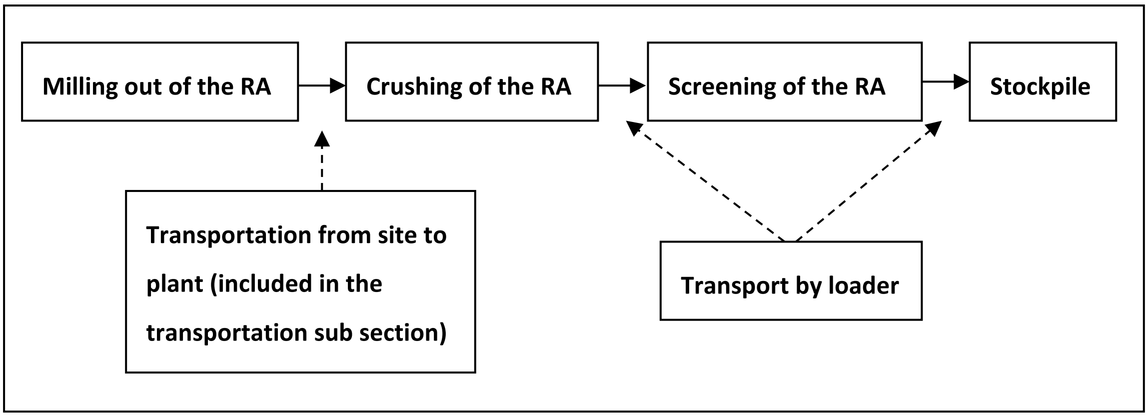

Figure 10: RA Procurement Phase

The process shown in Figure 10 does not include the transportation from the site to the asphalt plant. The four parts are defined below (Stander, 2013). The energy consumptions only include the primary energy consumption of the processes which are the diesel consumption.

- Milling of the current aged asphalt that is used as RA. This asphalt is milled out to a depth of 85mm. The average density of the RA is 2500 kg/m^3 (Stander, 2013). The milling machine used in this project is a Wirtgen W2000. Energy consumption data was obtained from the Wirtgen W2000 catalogue which mainly includes the consumption of diesel (Wirtgen Group, 2010)

- After the RA has been milled out it is taken to the asphalt plant where it is further broken down by an impact crusher. The diesel consumption as well as the crushing capacity of these crushers were provided by the asphalt supplier, National Asphalt (Stander, 2013).
- The RA is screened to stockpile the different aggregate sizes. This process takes place on the premises of the asphalt production plant after it has been broken down by the impact crusher. The screening machine that is used on this project is a Terex Finlay 683. The diesel consumption and the screening capacity were obtained from the Terex catalogue as well as through communication with the asphalt supplier, National Asphalt (Stander, 2013) (Finlay Screening and Crushing Systems Pty Ltd, 2010).
- A loader is required to take the screened RA to the stockpiled area. This loader's energy consumption only includes diesel consumption (Stander, 2013).

Table 20 shows the calculations of the energy demand of the procurement of the RA.

Table 20: RA Procurement Energy Demand

Nr.	Variables	Values	Source or calculation
	Milling of RA (Wirtgen W2000)		
1	Speed (m/min)	10.00	(Wirtgen Group, 2010)
2	Milling depth (m)	0.085	(Stander, 2013)
3	Energy demand (MJ/m^2)	2.91	(Wirtgen Group, 2010)
4	RA average density (kg/m^3)	2500.00	(Stander, 2013)
5	Energy demand per ton (MJ/ton)	13.70	((3 ÷ 2) ÷ 4) × 1000
	Crushing of the RA (Terex impact crusher)		
6	Diesel consumption (L/h)	34	(Stander, 2013)
7	Diesel density (20-60°C)(kg/m^3)	885	
8	Crushing capacity (ton/h)	150	(Stander, 2013)
9	Diesel consumption for 1 ton RA(L)	0.22667	8 ÷ 6
10	Diesel consumption for 1 ton RA(m^3)	0.00023	9 ÷ 1000
11	Diesel demand for 1 ton RA(ton)	0.00020	(10 × 7) ÷ 1000
12	Diesel energy demand(MJ/ton)	45600	(Stotsko, 2011)
13	Screening energy demand (MJ/ton)	9.15	11 × 12

Table 20: RA Procurement Energy Demand (continues)			
	Screening of RA (Terex Finlay 683)		
Nr.	**Variables**	**Values**	**Source or calculation**
14	Diesel consumption (L/h)	15	(Stander, 2013)
15	Diesel density (20-60°C)(kg/m³)	885	
16	Screen capacity (ton/h)	150	(Stander, 2013)
17	Diesel consumption for 1 ton RA(L)	0.1	14 ÷ 16
18	Diesel consumption for 1 ton RA(m³)	0.0001	17 ÷ 1000
19	Diesel demand for 1 ton RA(ton)	0.0000885	(18 × 15) ÷ 1000
20	Diesel energy demand(MJ/ton)	45600	(Stotsko, 2011)
21	Screening energy demand (MJ/ton)	4.04	19 × 20
	Loader required for RA screening and stockpiling (CAT 928)		
22	Diesel consumption (L/h)	15	(Stander, 2013)
23	Loader energy demand (MJ/ton)	4.04	Same as the screening of the RA
24	**Total RA energy demand (MJ/ton)**	**30.92**	**13 + 21 +23**

It is difficult to verify the energy consumption calculated above. From available research it was however found by (Stripple, 2001) that the milling of RA consumes 12 MJ/ton which is close to the 13.7 MJ/ton found through the calculations in this section. The RA screening and crushing processes can vary because of the use of different impact crushers and screening plants which have different diesel consumptions. According to (Stripple, 2001) the processing of RA consumes 42 MJ/ton which is a bit more than the 30.92 MJ/ton calculated in this study. However, because of the varying machinery and the possible inclusion of other energy consuming components the value calculated in this analysis is considered sufficient as it is based on the process defined in this section.

Warm Mix Asphalt (WMA) Additive:

The WMA technology that is used on the N1 project is called Sosowax 1655 and is produced locally by Sasol (Nortjè, 2013). This WMA technology reduces the mixing temperature as well as rejuvenates the residual bitumen of the RA (softens the residual hard bitumen). Sasowax 1655 is modified for high performance in mixes with high percentages of RA (Lewis, 2011).

The quantity of these additives may vary between 0.5 to 4% of the binder volume (Nortjè, 2013). The quantity that is required for the N1 project was determined by Sasol (the manufacturer) and National Asphalt (asphalt supplier) to be at a percentage of 0.7% of the binder volume (Stander, 2013). This value is calculated by assessing the amount of residual bitumen that can be extracted from the RA as well as the amount of virgin bitumen that will be added. The Sasowax is thus added to combine these two bitumen types to reach a specific grade of bitumen that is required for the project.

No data is available on the energy consumption of the manufacturing of the Sasowax 1655. However, the study by (Zaumanis, 2010) states that the energy consumption of the manufacturing of Sasobit (WMA additive) is similar to the manufacturing of bitumen (Zaumanis, 2010). It is thus assumed that the energy consumption for the procurement of the Sasowax 1655 is the same as the bitumen, which is 5552.5 MJ/ton (Table 18). The quantity of WMA additive used is small and this variation will have little effect on the results of the analysis.

5.3.2 Transportation

This section quantifies the transportation energy consumption. It includes the transportation of all raw materials to the asphalt plant as well as the transportation of the asphalt after production to the construction site where it will be laid. Table 21 shows the energy consumption per ton of the material that has to be transported. It has to be noted that a load is one truck and that the distance for one load includes the return trip of the truck as well. The diesel consumption is also an average between the full and the empty load diesel consumption.

The truck sizes, their diesel consumption as well as the distances to the sources of the materials were obtained through conversations with the contractor on site and the asphalt supplier, National Asphalt (Stander, 2013).This data is thus not theoretical but are the actual values that were measured on this project. A diesel energy demand of 45600MJ/ton was used (Stotsko, 2011).

Table 21: Transportation Energy Demand (Stander, 2013)

Nr.	Variables	Aggregate from Elandsrand (Carletonville) to plant	Bitumen from Sapref (Durban)	Lime from Lime Distributors (Vereeniging) to plant	WMA additive from Sasol (Sasolburg) to plant	RA from the project site to plant	New asphalt from plant to site
1	**Distance for one load (km)**	152	1134	50	50	40	40
2	**Diesel consumption (km/l)**	1.8	1.75	1.75	2.8	1.9	1.9
3	**Load capacity (tons)**	27	30	33	13	13	13
4	**Diesel consumption for 1 ton material(L)**	3.13	21.60	0.87	1.37	1.62	1.62

Table 21: Transportation Energy Demand (continues)							
Nr.	**Variables**	**Aggregate from Elandsrand (Carletonville) to plant**	**Bitumen from Sapref (Durban)**	**Lime from Lime Distributors (Vereeniging) to plant**	**WMA additive from Sasol (Sasolburg) to plant**	**RA from the project site to plant**	**New asphalt from plant to site**
5	**Diesel consumption for 1 ton material(m^3)**	0.0031	0.022	0.00087	0.0014	0.0016	0.0016
6	**Diesel demand for 1 ton material(ton)**	0.00277	0.01912	0.00077	0.00122	0.00143	0.00143
7	**Diesel energy demand(MJ/ton)**	**126.22**	**871.69**	**34.94**	**55.43**	**65.35**	**65.35**

The following equation was used to obtain the values in row 7 (1, 2 and 3 refers to the line values in Table 21):

$((885 \times ((1 \div 2) \div 3) \div 1000) \div 1000) \times 45600.$

The 885 kg/m³ is the density of diesel and the 45600 MJ/ton is the energy demand of one litre of diesel.

5.3.3 Asphalt Production

The asphalt production phase in this study only looks at the production plant's energy consumption which is the primary energy consumer of the asphalt production phase. The asphalt production process makes use of three forms of energy namely: light burning fuel (LBF), heavy fuel oil (HFO) and electricity (Stotsko, 2011). Natural gas can also be used to fuel the mixing drum if it is available, but on the N1 project no gas lines were near the plant premises and HFO was thus used.

- LBF: This fuel is used to fuel the burners that keep the bitumen warm next to the plant before it is used. These burners keep the bitumen at a temperature of 160°C even if the plant is not operational. It is thus difficult to quantify how much fuel is used for one ton of asphalt. These burners consume 7500 litres of LBF per month (Stander, 2013). It has thus been decided to make certain assumptions to rework this consumption to consumption per ton of asphalt as indicated below. It is assumed that the burners heat the bitumen 6 days a week for 10 hours a day. The total LBF consumption for the whole month is thus been divided into these hours. It has thus been assumed that the burners use all the fuel within these asphalt production hours. It was also assumed that the energy demand of one ton of LBF is the same as one ton of diesel which is equal to 45600 MJ/ton. By doing this the use of LBF is also included into the analysis. The energy consumption of the LBF is minimal (11.18 MJ/ton as seen in the table below) and this variation will have a minimal effect on the results.

- HFO: HFO is used to fuel the large burner flame inside the plant drums to heat and dry the aggregate. According to the contractor the plant uses eight litres of HFO to produce one ton of asphalt (Stander, 2013). This value was determined by the contractor through years of historical data gathered from different asphalt plants. This value may vary due to the amount of moisture in the aggregate (a variation in the drying of the aggregate occurs).
- Electricity: The electricity is used to operate the conveyers, blowers, lights, all electrical controllers, etc. According to a study by Sabita electricity makes up 12% of the energy consumption of the asphalt plant in South Africa (Sabita, 2011). The energy of LBF and HFO are thus assumed to be 88% of the total plant energy and was then reworked to 100% to get the energy consumption of the electricity.

According to a study conducted by Sabita and Carbon & Energy Africa (Pty) Ltd (Stotsko, 2011) the average energy consumption of an asphalt plant in South Africa is between 300 and 350 MJ/ton of asphalt. This value was obtained by working back from the annual average asphalt production. It is thus an average for all asphalt plants. The value calculated in this study is 375.41 MJ/ton as seen in Table 22. This energy consumption calculated in Table 22 can thus be seen as sufficient as this is a specific value for the specific plant which is close to the average value calculated by (Stotsko, 2011).

Table 22: Asphalt Production Energy Demand			
Nr.	**Variables**	**Value**	**Source or calculation**
	Light Burning Fuel (LBF)		
1	Monthly consumption (L)	7500	(Stander, 2013)
2	Daily production time (hours)	10	Assumed
3	Number of production days a month	26	Assumed
4	Plant production rate (ton/hour)	100	
5	LBF consumption for 1 ton of asphalt (L)	0.288	(1 ÷ (2 × 3)) ÷ 4
6	LBF consumption for 1 ton of asphalt (m^3)	0.00029	5 ÷ 1000
7	Density of LBF (kg/m^3)	850	
8	LBF consumption for 1 ton of asphalt (ton)	0.000245	(6 × 7) ÷ 1000
9	Energy demand for 1 ton LBF (MJ/ton)	45600	(Stotsko, 2011)
10	LBF energy demand (MJ/ton)	11.18	8 × 9

Table 22: Asphalt Production Energy Demand (continues)			
	Heavy Fuel Oil (HFO)		
Nr.	**Variables**	**Value**	**Source or calculation**
11	HFO consumption for 1 ton of asphalt (L)	8	(Stander, 2013)
12	HFO consumption for 1 ton of asphalt (m³)	0.008	11 ÷ 1000
13	Density of HFO (kg/m³)	930	
14	HFO consumption for 1 ton of asphalt (ton)	0.00744	(12 × 13)/1000
15	Energy demand for 1 ton HFO (MJ/ton)	42900	(Stotsko, 2011)
16	HFO energy demand (MJ/ton)	319.18	14 × 15
	Electricity (12% of total energy)		
17	LBF + HFO percentage of production energy	88	(Sabita, 2011)
18	LBF + HFO (MJ/ton)	330.36	10 + 16
19	Electricity energy demand (MJ/ton)	45.049	18 × (100 ÷ 17) - 18
20	**Total asphalt production energy demand (MJ/ton)**	**375.41**	18 + 19

5.3.4 Construction

This section quantifies the energy consumption of the laying of the asphalt as well as the compaction of the asphalt. The analysis includes only the primary energy consumption sources which are the diesel consumption of the machines.

Laying of the Asphalt:

The laying of the asphalt was done with a Voegele 1800-2 paver and the calculations are shown in Table 23. The paver's diesel consumption and speed was obtained from the product catalogue and from the asphalt supplier, National Asphalt (Stander, 2013).

It is assumed that the paver and the rollers are static (not utilised) for an additional 10% of their running time. This assumption is made to improve the accuracy of the calculation. It is however not necessary to conduct a sensitivity analysis on this percentage as it will have little to no effect on the results as the energy consumption of the paver and the rollers is very low.

	Table 23: Asphalt Paving Energy Demand		
Nr.	**Variables**	**Value**	**Source or calculation**
	Voegele 1800-2 Paver		
1	Diesel consumption (L/h)	30	(Stander, 2013)
2	Diesel density (20-60°C)(kg/m³)	885	
3	Paving speed (km/h)	0.84	
4	Length of the lane(km)	10	
5	Total diesel consumption(L)	357.14	(1 ÷ 3) × 4
6	Total diesel consumption(m³)	0.36	5 ÷ 1000
7	Total diesel consumption(ton)	0.32	(6 × 2) ÷ 1000
8	Diesel energy demand(MJ/ton)	45600	(Stotsko, 2011)
9	Energy demand (MJ)	14412.86	7 × 8
	10% of the fuel added for a non-utilised paver		
10	**Total energy demand (MJ)**	**15854.14**	**9 × 1.1**
11	**Total asphalt tonnage**	**7362.45**	
12	**Total energy demand (MJ/ton)**	**2.15**	**10 ÷ 11**

<u>Asphalt Compaction:</u>

The compaction process was analysed by looking at the different rollers used as well as the amount of repetitions they do during compaction. The different types of rollers as well as the amount of rolling repetitions were obtained from the asphalt supplier, National Asphalt (Stander, 2013). The compaction energy demand is shown in Table 24.

Table 24: Asphalt Compaction Energy Demand			
Nr.	**Variables**	**Value**	**Source or calculation**
	Steel Wheeled Rollers		
1	Diesel consumption (L/h)	3	(Stander, 2013)
2	Diesel density (20-60°C)(kg/m³)	885	
3	Rolling speed (km/h)	5	
4	Length of the lane (km)	10	(Stander, 2013)
5	Total number of passes by the roller	4	(Stander, 2013)
6	Total distance covered by this roller (km)	40	4 × 5
7	Total diesel consumption(L)	24.00000	(1 ÷ 3) × 6
8	Total diesel consumption(m³)	0.02400	7 ÷ 1000
9	Total diesel consumption(ton)	0.02124	(8 × 2) ÷ 1000
10	Diesel energy demand(MJ/ton)	45600	(Stotsko, 2011)
11	Total energy demand (MJ)	968.54	9 × 10

Table 24: Asphalt Compaction Energy Demand (Continues)			
	Pneumatic Rollers		
Nr.	**Variables**	**Value**	**Source or calculation**
12	Diesel consumption (L/h)	8	(Stander, 2013)
13	Diesel density (20-60°C)(kg/m³)	885	
14	Rolling speed (km/h)	6	
15	Length of the lane (km)	10	(Stander, 2013)
16	Total number of passes by the roller	4	(Stander, 2013)
17	Total distance covered by this roller (km)	40	15 × 16
18	Total energy demand (MJ)	2152.32	10 × 13 × ((12 ÷ 14) × 17)/1000000
	Three Point Rollers		
19	Diesel consumption (L/h)	7	(Stander, 2013)
20	Diesel density (20-60°C)(kg/m³)	885	
21	Rolling speed (km/h)	6	
22	Length of the lane (km)	10	(Stander, 2013)
23	Total number of passes by the roller	3	(Stander, 2013)
24	Total distance covered by this roller (km)	30	Calculations
25	Total energy demand (MJ)	1412.46	10 × 20 × ((19 ÷ 21) × 24)/1000000
	10% of the fuel added for non-utilised rollers		
26	**Total compaction energy demand (MJ)**	**4986.66**	**1.1 × (11 + 18 +25)**
27	**Total asphalt tonnage**	**7362.45**	
28	**Total compaction energy demand (MJ/ton)**	**0.68**	**26 ÷ 27**

5.3.5 Service Life

In this study the service life energy consumption is defined as follows:

The energy consumed by the maintenance and rehabilitation of the asphalt layer until it reaches the end of its design period, which is 15 years. The design period of 15 years was obtained from the consulting engineer on the project and will thus be used in this study. The scope of this service life analysis is limited as a number of assumptions were made. These assumptions were made as the scope of knowledge required to accurately analyse the service life of these mixes are broad and would require a large amount of research which will push the study out of its current scope. Factors that were not considered and excluded from the scope of the service life analysis include: rutting and fatigue in base layers, rutting in surface layer, stresses and strains, plotting of different fatigue comparison graphs as well as analysis methods to determine the fatigue, rutting, stresses and strains.

The maintenance and rehabilitation of the different mix models (defined in Chapter 4) must thus be investigated to determine the magnitude of the energy consumption in this phase. The pavement undergoes maintenance and rehabilitation when the road deteriorates to such a degree that it needs to be replaced or fixed. It is however complicated to determine the exact time during the 15 year life span when this deterioration reaches this degree. A standard rehabilitation schedule is thus estimated at the design phase of the project. This deterioration occurs when the pavement's performance is not sufficient to maintain the required traffic load. It is even more complicated to determine the performance of the RA and WMA mixes as these technologies are new to South Africa and their performance is still one of the topics under investigation (as concluded from the interviews in Chapter 3).

It was thus decided to investigate current literature in South Africa to obtain an indication of how these technologies influence the performance of the asphalt pavement. This is done to estimate and compare the rehabilitation schedules of the different mix models. Two concepts were identified that can act as indicators to help compare the performance of these technologies with the conventional HMA. They are discussed in the following two subsections.

A. <u>Fatigue performance and strain:</u>

Fatigue cracking is damage that is caused by repeating loads on an asphalt pavement structure. This fatigue cracking is a concept that is based on a cumulative damage concept. This concept considers the cumulative load repetitions on the pavement structure and its relation to the tensile strain at the bottom of the asphalt layer. Fatigue performance is considered as a predominant concern in asphalt pavement structures and can thus be used as an indicator to compare the performance of the RA and WMA technologies and the conventional HMA. (Mbaraga, 2011)

A road is designed to be able to maintain a certain bearing capacity. Bearing capacity thus indicates that a road can carry a traffic spectrum up to a certain volume. Bearing capacity is expressed in E80's. E80's are standard axle (80kN) repetitions. It is thus assumed that this number of E80's do the same damage to the pavement structure as the equivalent traffic. (Committee of Land Transport Officials (COLTO), 1996)

A study by Mbaraga (2011) investigates the fatigue performance of RA and WMA technologies. Fatigue lines were constructed from lab testing. A fatigue line plots the number of E80 loads against the tensile strain measurement at the bottom of the asphalt layer. These lines can thus be used to determine the strain at a specific E80 loading. It was decided to determine the strain for different mixes to see what the magnitudes of these strains are and how they differ. The study by (Mbaraga et al., 2011) includes different asphalt mixes that includes the use of RA and WMA technology. The design E80's can be calculated from the project data. The strain at the design cumulative load can thus be determined. The design bearing capacity was calculated with the help of the Technical Recommendations for Highways (TRH4) (Committee of Land Transport Officials (COLTO), 1996). Table 25 shows the calculations to determine the design bearing capacity. The third column indicates the sections in the TRH4 that were used as well as which data was obtained from the project document.

Table 25: Computing the Cumulative E80's		
Average Daily E80's (ADE)	1673	(V&V Consulting Engineers, 2012)
Annual Average Daily E80's (AADE)	1589.35	Table 9, 4 lanes
Annual growth rate	2	(V&V Consulting Engineers, 2012)
AADE (initial, 2013)	1653.56	Formula 4.4, 2 years
Prediction years	15	(V&V Consulting Engineers, 2012)
Cumulative factor	6438.34	Table 12
Total E80's	**10646178.36**	**Formula 4.6**

This total E80's value is thus the predicted traffic load that the pavement in the case study will undergo during its design period of 15 years. Fatigue lines are now used to determine the strain at the bottom of the asphalt layer. Table 26 indicates the strains that were determined of the fatigue lines as well as the sources that were used to obtain these lines. Table 26 also shows the mixes that were selected from the indicated sources as well as the corresponding mix model (as defined in Chapter 4). These mixes each have their own unique fatigue line.

Table 26: Design Strains			
Mix models	**Selected mix**	**Source**	**Strains (from mix fatigue line)**$(\mu\varepsilon)$
HMA, reference	HMA, 10% RA 60/70	(Mbaraga et al., 2011)	73
HMA, 20% RA	HMA 20% RA A-E2(SBS) 80/100	(Mbaraga, 2011)	95
WMA, 40% RA	WMA 40% RA A-E2(SBS + Sasobit) 80/100	(Mbaraga et al., 2011)	56

These mixes include a conventional HMA as well as asphalt that use RA and WMA technology (as used in the case study). These strains are very low and it indicates that the different mixes will reach the required performance for which it is designed. Table 27 shows guidelines that were constructed in a study by Arthur Taute (2011) for the evaluation of fatigue performance.

Relative Fatigue Performance	Table 27: Number of Repetitions to Failure for Strains (Millions) at 5°C		
	Low Strain	Medium Strain	High Strain
	180 - 230	320 - 370	380 - 430
Good	> 2.4	> 0.13	> 0.06
Medium	1.0 to 2.4	0.03 to 0.13	0.02 to 0.06
Poor	< 1.0	< 0.03	< 0.02

The design E80's (load repetitions) is 10.6 million and the range of strains that were derived from the fatigue lines in Table 26 is between 56 and 95. Table 27 indicates that a strain between 180 and 230 is considered a low strain and it also indicates if the number of repetitions is higher than 2.4 million the fatigue performance is considered to be good. Even though Table 27 applies for measurements at a temperature of 5°C (as the onsite temperatures will be much higher and will thus increase the strain) the strains in this study is much lower than the "Low Strain requirement" and the number of repetitions is much higher than the "good fatigue performance limit" of 2.4 million.

By looking at this basic fatigue performance analysis it indicates that the three mixes in Table 26 will have a good enough fatigue performance to fulfil the needs of the project. It also indicates that the conventional HMA and the RA and WMA technology mixes' fatigue performance are both sufficient and that they can adhere to the same rehabilitation schedule.

B. <u>Dissipated Energy:</u>

Dissipated energy is related to fracture parameters in fracture mechanics. It is thus related to the load repetitions and the energy that is transferred to the pavement structure. The energy required to fail a pavement structure can be derived from the curve obtained from a flexural beam fatigue test. The area under the number of loads and energy curve is equal to the dissipated energy. (Mbaraga et al., 2012)

A study by Van Dijk (1977) produced a model that allows the number of loads to be correlated to the dissipated energy. This model thus allows you to estimate the energy that needs to be applied to a certain pavement structure to have the same effect as a certain number of loads.

Alex Mbaraga (2012) investigated and derived dissipated energy equations for certain mixes that makes use of RA and WMA technologies. It was decided to input the design bearing capacity (E80's) into these dissipated energy equations to determine the energy required to reach this bearing capacity for each of the mixes analysed by Mbaraga (2012). Table 28 indicates the dissipated energy for some mixes.

Table 28: Dissipated Energy Analysis		
Reference	HMA,10% RA 60/70	250.75 MPa
10% RA, organic additive	WMA,10% RA 60/70 organic additive	268.36 MPa
10% RA, chemical additive	WMA, 10% RA 60/70	364.96 MPa
20% RA, WMA additive	WMA 20% RA 80/100 Elastomer	467.43 MPa
20% RA, WMA additive	WMA 20% RA 80/100 Plastomer	515.24 MPa

As indicated in Table 28 the amount of energy required by the WMA mixes is more than the reference HMA mix. The WMA mixes thus requires more energy to reach the designed bearing capacity. From a fatigue behaviour point of view the RA and WMA mixes requires more energy to reach the bearing capacity than the reference HMA mix and does thus not show a worse fatigue performance than the conventional HMA.

The dissipated energy principle can be used to indicate that the RA and WMA technologies' fatigue performance is the same or even better than the conventional HMA mix.

<u>Maintenance and Rehabilitation Energy Consumption:</u>

By looking at these two indicators it has been decided that the same maintenance and rehabilitation will apply for both the conventional HMA as well as for the RA and WMA technologies' mixes. There are a number of maintenance and rehabilitation solutions.

According to a study by Jenkins (2011) the following solutions are common in South Africa for heavy-duty pavements:

1. To patch the deteriorating areas and to apply an overlay of a relatively thick asphalt layer.

2. To mill of the existing asphalt and to replace it with a similar asphalt overlay (this also includes repair of the underlying granular layer).

3. To recycle the upper part of the old asphalt by stabilising it with a cement agent, then construct a new base layer (crushed stone or asphalt) and to apply an overlay of an asphalt wearing course.

4. Recycle the upper portion of the existing pavement with a bitumen stabilising agent and apply an asphalt wearing course.

It has been decided to use the second solution as it uses the same procedure as the current maintenance in the case study. This solution is ideal for this study as the asphalt layers that are rehabilitated in the solution also include a UTFC layer as well as a conventional HMA layer (the same as in the case study). Jenkins (2011) conducted an extensive study on the environmental impact of maintenance and rehabilitation and has calculated the energy consumption of the solution selected above. It was thus decided to use the energy analysis results in this study. It is assumed after looking at the fatigue and dissipating energy principles that the BTB layer will have sufficient performance to last its design 15 years. The service life of the UTFC surface layer is however between 6 and 8 years (Jenkins & Collings, 2011). It was thus decided to replace the surfacing layer after 7 years as a maintenance measure. Figure 11 shows the maintenance after 7 years.

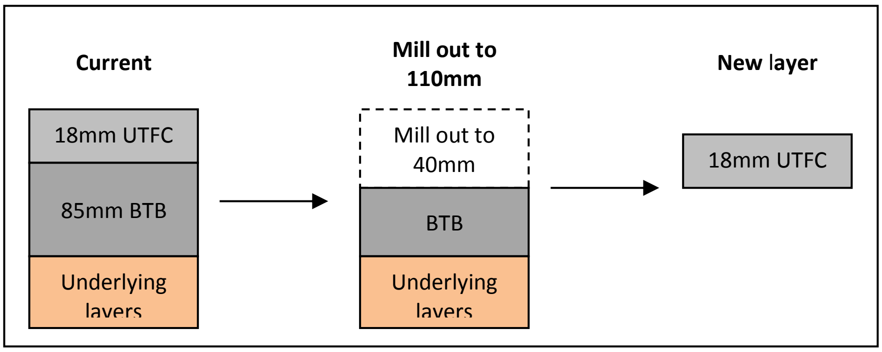

Figure 11: Maintenance after 7 Years

The mill and replace option's energy consumption is adopted from the study done by Jenkins (2011). Table 29 indicates the calculations that were required to convert Jenkins (2011) energy consumption to the quantities of this study.

Table 29: Energy Consumption of Service Life

Nr.	Variables	Value	Source or calculations
1	Mill and Replace of UTFC energy demand for 10 000m² (MJ)	579000	(Jenkins & Collings, 2011)
2	Milling depth after 7 years (m)	0.03	
3	UTFC density of the N1 project (kg/m³)	2500	Assumed
4	**Energy consumption for maintenance (MJ/ton)**	**579.00**	

It can thus be concluded that the fatigue performance of the different mix models (for the BTB layer) is considered to be sufficient for the design bearing capacity and their maintenance and rehabilitation plan will thus be the same. It was also decided to implement the values that were calculated by Jenkins (2011) for the selected rehabilitation solution (mill and replace) as the study was done extensively and it was done on a similar pavement structure than the one in the case study. The pavement will undergo maintenance during its lifespan after 7 years where the UTFC layer will be replaced. A value of 579 MJ/ton will be used as the service life's energy consumption.

5.3.6 End of Life

According to a study by Santero (2010) the environmental impact of the end of life phase of asphalt pavement depends on the ultimate fate of the asphalt as well as the constituent of the material (which is very difficult to predict). According to Santero (2010) there are three main end of life options that the asphalt pavement can undergo (Shown in Figure 12).

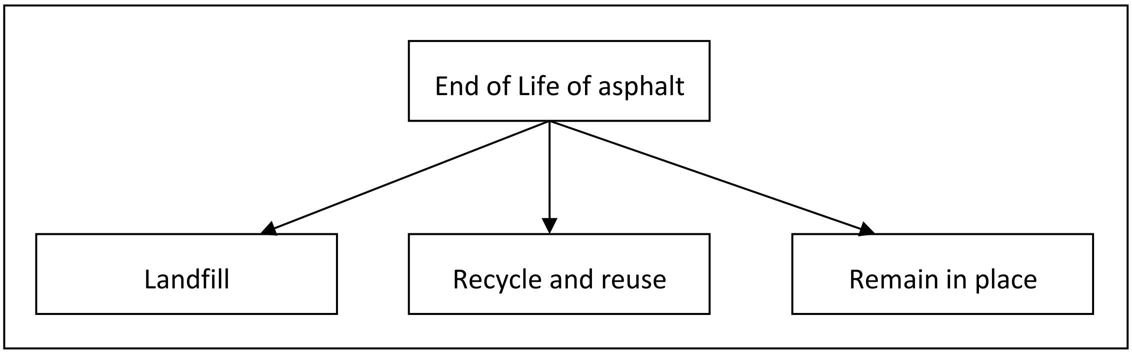

Figure 12: End of Life Options

A. Landfill

This option involves the demolition, transportation and land filling of the demolished asphalt. The environmental impact of the land filling option has been sufficiently studied and can easily be applied to a LCA. (Santero, 2010)

B. Recycle and reuse

The benefits of recycling asphalt are overlooked when land filling is assumed in a LCA. Studies on the recycling value of asphalt are however limited. A study by Federal Highway Administration and the Environmental Protection Agency (1993) indicated that 80% of asphalt materials are reused or recycled at the end of its life. This value seems to be very high, especially for South Africa but it is a clear indication that asphalt is being reused and that recycle and reuse is a better end of life option for the LCA than the land filling option. (Federal Highway Administration and the Environmental Protection Agency, 1993)

C. Remain in place

This option assumes that the old asphalt is used at a supporting layer for new surface layers. The old asphalt is thus left as it is and adds structural value to the new pavement structure. The environmental impact this option has on the new pavement structure is difficult to quantify as the old asphalt may increase the life of the new structure which may improve the new pavements environmental impact (longer service life and reduced maintenance). This is very complex to determine. (Santero, 2010)

Selected end of life option

In the Santero (2010) study he investigates 12 LCA studies. Of the 12 only four included the end of life phase to their LCA. Of the four only two did a quantitative analysis of which one used the landfill option and the other the recycle and reuse option. These quantitative analyses were done on a prediction of what is going to happen to the asphalt which is a large uncertainty. It can thus be concluded that LCA literature provides very little insight into the impact of the end of life phase on the entire life cycle of the asphalt and it is difficult to predict what the end of life option is going to be.

For the purpose of this study the end of life option that is selected is the recycle and reuse option as it seems to be the most likely to happen and that this study also investigates the benefits of RA.

According to Santero (2010) the recycling impact of asphalt can be simplified in the following equation.

$$Recycling\ impact = Recycling\ process\ impact - Landfill\ not\ used - aggregate\ saved - binder\ saved$$

The recycling process impact has already been quantified in this study which includes the removal, transportation and preparation for reuse. The aggregate and binder savings for the end of life of the asphalt is almost impossible to predict as it is unknown in what asphalt mix and in what quantities the RA will be reused. This paper however quantifies the aggregate and binder savings caused by the recycling of the asphalt and an indication of the savings can be concluded from those results.

It was thus decided that the end of life phase will yield no energy consumptions (to avoid double calculations) as the following energy consumption components of the recycling impact have already been included in the study:

- The recycling process of the old asphalt which provides the RA for the case study project,
- The aggregate and binder energy savings because of the use of the RA.

It was felt that rather than predicting what is going to happen at the end of the new asphalt's life (which is in 15 years) that the recycling of the previous asphalt in the case study project will rather be used which produces more accurate results.

5.4 Results Quality Assurance

The previous sections defined and calculated the contribution of each phase to the energy consumption of the asphalt life cycle. These calculated contributions are only based on the case study project and literature. It was thus decided to do result quality assurance to find out if a variation in the data obtained from the sources in this LCA does have an impact on the final energy consumption results and if the input values used are realistic.

The different phases of HMA that was analysed in this study (procurement, production, construction, service life and end of life) are each made up of factors that cumulatively make up the energy consumption of the phases. Example: the production phase contains Heavy Fuel Oil (HFO), Light Burner Fuel (LBF) and electricity. It was decided to list all these factors and to show their energy consumption to the final asphalt life cycle energy consumption. It was then decided to select the top five contributors and conduct sensitivity analyses on these factors. The variation of each of these factors that is used in the sensitivity analyses is obtained from asphalt suppliers and literature. After conducting the sensitivity analyses the final results are discussed.

The four mix models that are analysed are the following:

- HMA Reference,
- HMA with 20% RA,
- WMA with 0% RA,
- WMA with 40% RA.

Table 30 shows the contributions of the different factors to two of the mixes. The five top contributors are also highlighted in Table 30.

Table 30: Energy Contributions				
Contributing factors	HMA reference		WMA with 40% RA	
	Total energy (GJ)	Contribution (%)	Total energy (GJ)	Contribution (%)
Aggregate	315.62	2.82%	189.37	1.98%
Virgin Bitumen	1635.20	14.63%	899.36	9.40%
Lime	552.18	4.94%	552.18	5.77%
Reclaimed Asphalt (RA)	0.00	0.00%	86.50	0.90%
WMA additive	0.00	0.00%	11.45	0.12%
Transport	1623.24	14.53%	1337.56	13.98%
LBF	82.32	0.74%	65.85	0.69%
HFO	2349.92	21.03%	1879.93	19.64%
electricity	331.67	2.97%	265.33	2.77%
Asphalt Paving	15.85	0.14%	15.85	0.17%
Asphalt Compaction	4.99	0.04%	3.99	0.04%
Service Life	4262.86	38.15%	4262.86	44.54%
	11173.84	100.00%	**9570.24**	100.00%

It must be noted that the service life and lime contributions are high enough to be in the top five, but as their energy consumptions are the same for all the mixes it is irrelevant to conduct a sensitivity analysis on them (as it will have no effect on the end result even if values are varied). It must also be noted that the reason why they are the same is because these two factors are not affected by the technologies (according to the calculations and indicators used in this study) as all four mix models undergo the same maintenance.

The top five contributors are thus:

- Aggregate,
- Virgin bitumen,
- Transport,
- Heavy fuel oil (HFO),
- Electricity.

Sensitivity analyses are performed on each of these factors.

A. Aggregate

As no data on the energy consumption of aggregate procurement was available in South Africa an average was taken from different international studies' energy consumption. An average of 45.13 MJ/ton was used in the analysis. The literature values ranged between 38 MJ/ton and 50 MJ/ton. It was thus decided to a sensitivity analysis with a range of 38 MJ/ton to 55 MJ/ton. Figure 13 shows the impact different aggregate energy consumptions have on the total energy consumption of the project.

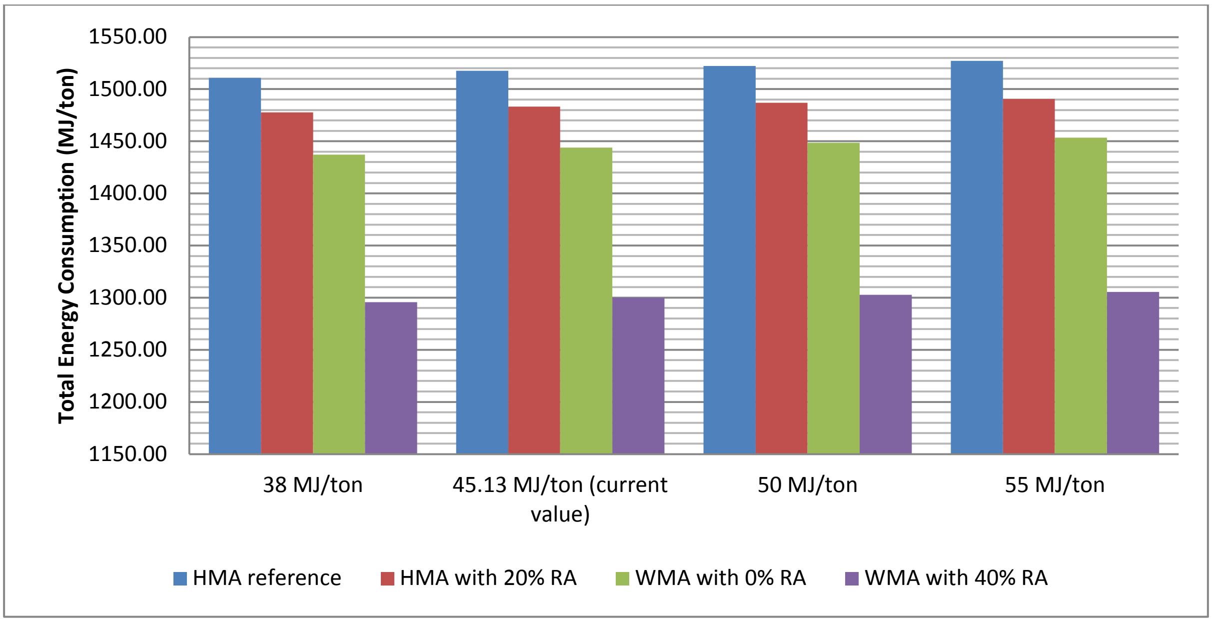

Figure 13: Aggregate LCA Sensitivity Analysis

Figure 13 shows that the variable energy consumptions do not have an effect on the influence of the technologies on the total energy consumption even if a value of 55 MJ/ton is used (which is higher than any literature investigated).

B. Virgin bitumen

Data on the energy consumption of the procurement of bitumen could also only be obtained from international literature. The values varied between 3200 MJ/ton to 6000 MJ/ton. It was however argued that South Africa is dependent on long oil shipping distances and the lower values were thus left out. The selected value for the study was the average of a range between 4900 MJ/ton and 6000 MJ/ton which is 5552.5 MJ/ton. The range selected for the sensitivity analysis is thus between 5500 MJ/ton and 7000MJ/ton (which is a very high value). Figure 14 shows the impact of different bitumen energy consumptions on the total energy consumption of the project.

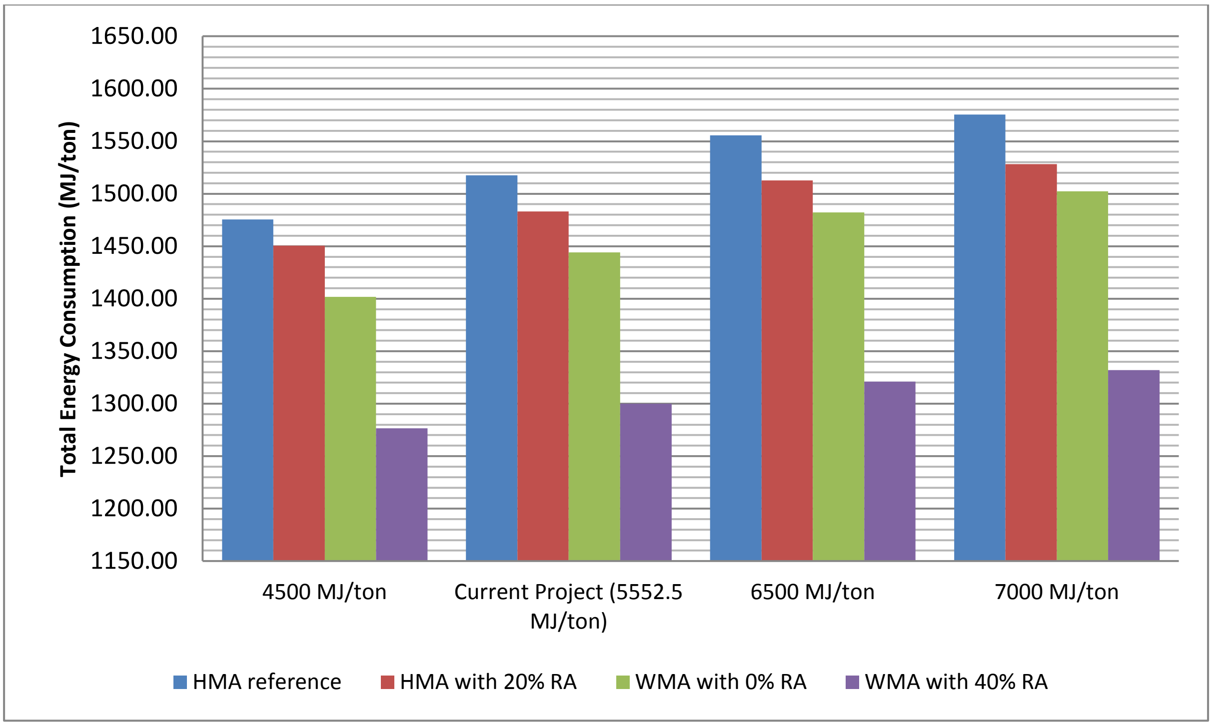

Figure 14: Bitumen LCA Sensitivity Analysis

Figure 14 shows that the varied energy demands of the bitumen do not affect the rank of the four mixes with regards to each other. It can however be noted that the 40% RA mix increases the difference in energy consumption over the reference mix even more as more energy savings is obtained.

C. Transport

Table 31 shows the variations that are used for the transport sensitivity analysis. The distances include a trip to and from the plant (thus for 1 load). The RA and new asphalt distances (from plant to paving site) are kept the same as it is assumed that the plant will not be further than 20km from the site.

Table 31: Transport Distance Variations (km)

	Aggregate	Bitumen	Lime	WMA additive	RA	New asphalt
Current project distances	152	1134	50	50	40	40
Option 1	200	1200	100	100	40	40
Option 2	300	1600	200	200	40	40
Option 3	400	2000	300	300	40	40

These values are inserted into the LCA spread sheet and the effect on the total energy consumption is shown in Figure 15.

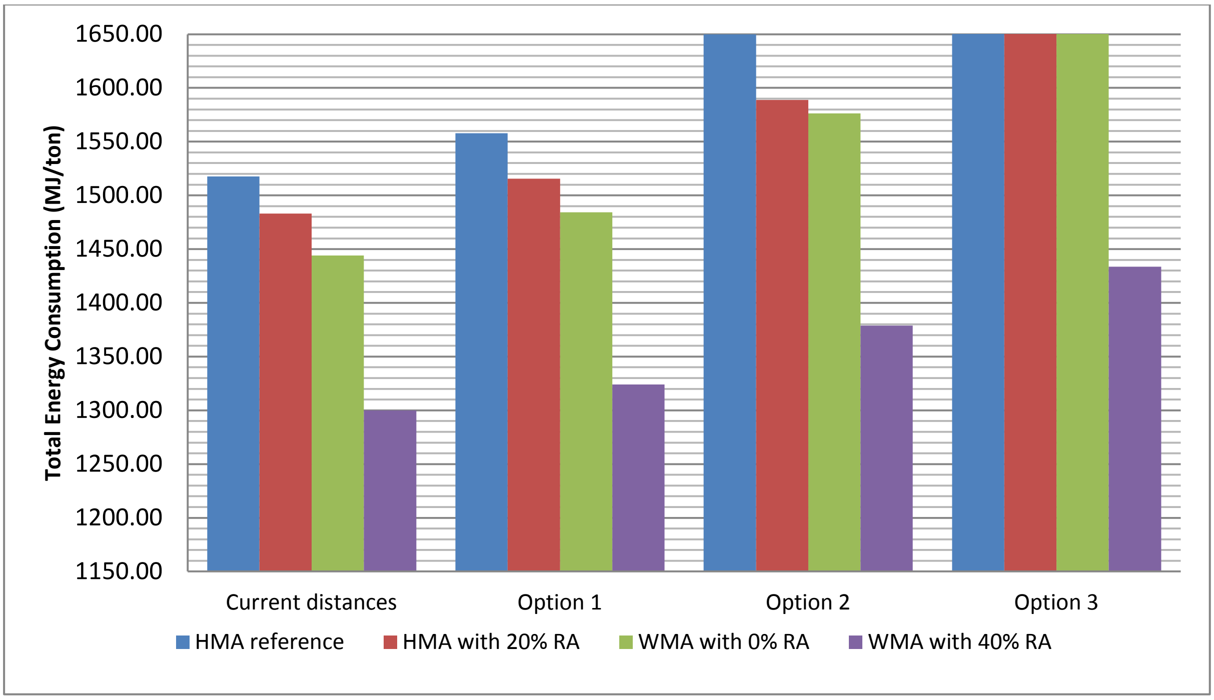

Figure 15: Transport LCA Sensitivity Analysis

The varying distance does affect the influence of the technologies on the mix models (the rank of the mixes does not stay the same). However it can be noted that the WMA with 0% RA consumes more energy than the HMA with 20% RA in Option 3. This indicates that the longer the haulage distances the more energy effective RA mixes become (as they reduce the haulage of bitumen and aggregate).

D. Heavy Fuel Oil (HFO)

The usage of HFO in the asphalt mixing process was discussed with an asphalt supplier, National Asphalt. National Asphalt consists of 16 asphalt plants that provide 30% of South Africa's asphalt. According to them the HFO consumption is dependent on the type of mix, and especially the moisture content of the aggregate. According to them their HFO consumption for a single plant varies between 5.5 l/ton to 10 l/ton. The sensitivity analysis is thus conducted between these values with an addition of 11l/ton also being added. The conversation with National Asphalt can be found in Appendix E-5. (Stander, 2013)

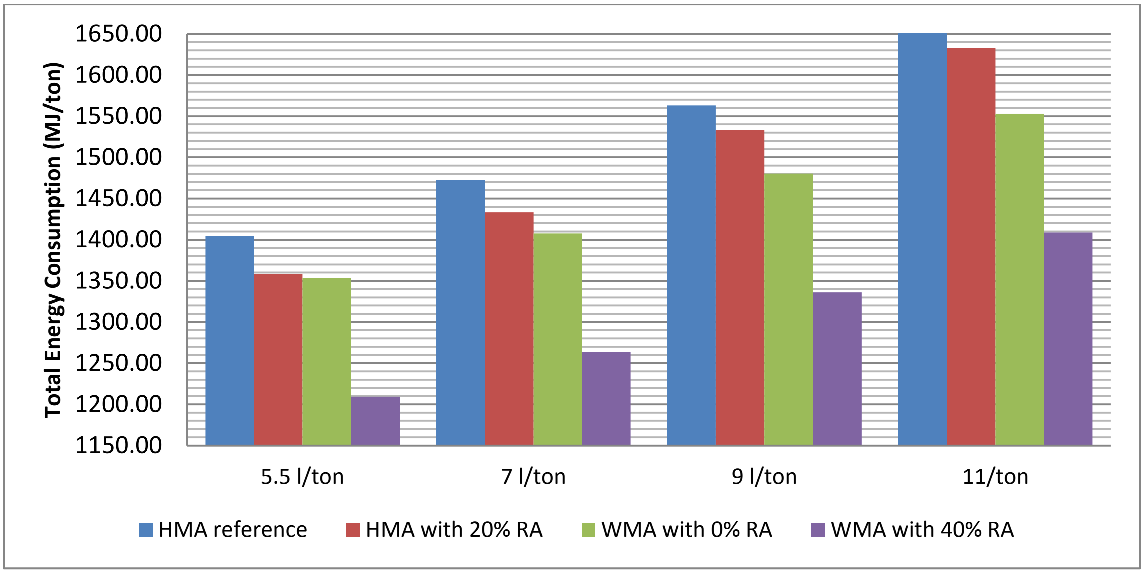

Figure 16: Heavy Fuel Oil LCA Sensitivity Analysis

Figure 16 shows the effect of the varying HFO consumptions on the total energy consumption. The varying HFO consumptions do not change the rank of the energy consumptions. It does thus not change the results that would be achieved by using the N1 project's HFO consumption of 8 l/ton.

E. Electricity

The electricity energy consumption was determined by a study done by Sabita that stated that the electricity energy consumption is 12% of the total asphalt plant energy consumption in South Africa (Sabita, 2011). As this is seen as a reliable source it was still decided to do a sensitivity analysis of the electricity energy demand that varies the percentage of electricity energy demand to the asphalt plant. A variation between 10% and 16% is used.

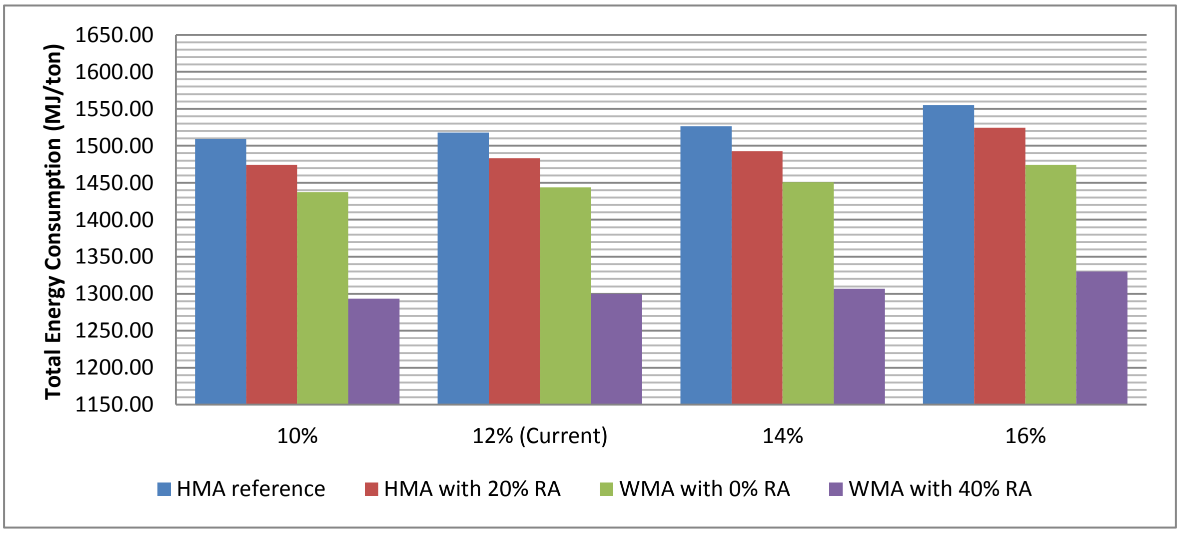

Figure 17: Electricity Sensitivity Analysis

Figure 17 shows the effect the varying energy contributions of electricity have on the total energy consumption. The varying values have no effect on the results apart from increasing the energy value slightly.

Sensitivity Analysis conclusion:

The top five contributors were selected and a sensitivity analysis was conducted on each of them. This was done to find out if the values used in the LCA is reliable and to find out what effect the varying input values have on the total energy consumption of the analysis. The most import was to find out if varying input values change the rank of the mix models' energy consumption as this would mean that the varying values have an effect on the impact of the RA and WMA technologies on the asphalt industry.

After conducting the five analyses it was founded that apart from the increase in energy consumption of all the mixes the varying values do not have an effect on the rank of the energy consumption of the mixes. It was also found that the values used in the LCA are realistic and that the case study can provide a realistic view into the impact of these technologies on the South African asphalt industry. The values that were used in the LCA are thus accepted and are discussed in the following section as the final results.

5.5 Results and Discussions

Table 32 shows the total energy consumption of the four mix models that was calculated by the LCA. It can be seen that the use of the RA and WMA technologies does reduce the energy consumption. The use of only RA technology saves 1.39% energy and the use of only WMA technology saves 4.65% of the energy that would have been used by the reference HMA mix (that uses no technology). Table 32 also shows that by using a combination of the two technologies a much larger energy saving can be obtained which is 12.19%.

Table 32: Energy Savings from Using the Technologies

Mix Model	Total Energy Consumption (MJ/ton)	Energy savings from technologies
HMA reference	1583.04	0%
HMA with 20% RA	1560.98	1.39%
WMA with 0% RA	1509.39	4.65%
WMA with 40% RA	1390.06	12.19%

Figure 18 shows the energy contributions of each of the five phases of the asphalt mixes. The service life energy consumption is seen as a constant as in the case of this analysis the same rehabilitation option was used for all four of the mixes. It can also be seen that the mix that only uses the RA technology (HMA with 20% RA) reduces the energy consumption of the material procurement phase and the transportation phase. This mix does however increase the production phase and the construction phase's energy consumption. The mix that only uses WMA technology reduces the production and construction phase's energy consumption but does not affect the procurement and transportation energy consumptions. The mix with the combination of technologies reduces the energy consumption in every phase except the service life phase.

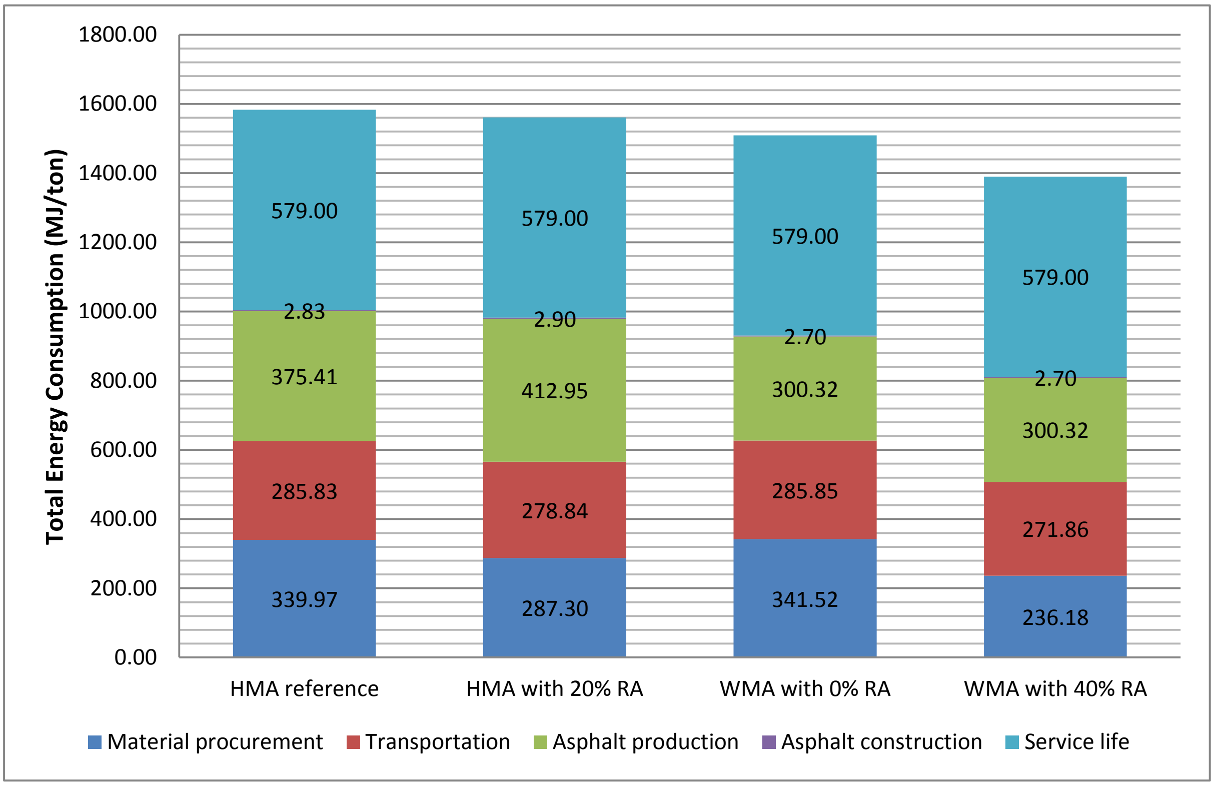

Figure 18: LCA Energy Consumptions

The following is observed of each technology from the results obtained from the analysis:

- **Reclaimed Asphalt (RA) Technology:**

The use of RA reduces the energy consumption of the procurement and the transportation phase. Table 33 shows these two phases as well as their contributing components.

Table 33: RA Technology Energy Savings

LCA Components		HMA reference (MJ/ton)	HMA with 20% RA (MJ/ton)	Energy savings
Procurement Phase	Aggregate	42.87	34.29	20%
	Virgin Bitumen	222.10	172.13	23%
	Lime	75.00	75.00	0%
	Reclaimed Asphalt (RA)	0.00	5.87	energy increase
	WMA additive	0.00	0.00	-
Transportation Phase	Aggregate	119.91	95.92	20%
	Virgin Bitumen	34.87	27.02	23%
	Lime	0.35	0.35	0%
	WMA additive	0.00	0.00	-
	RA	0.00	24.83	energy increase
	New asphalt	130.71	130.71	0%
		625.80	**566.13**	**10%**

Table 33 shows that the energy is reduced in the procurement and transportation phase as a result of reduced aggregate and virgin bitumen needs and haulages. The procurement and transportation of the RA does increase the energy usage. This usage is however too little to impact the net energy reduction. A total of 10% energy is thus saved in these two phases by RA technology.

RA technology does cause an increase in the asphalt production and construction phases as a result of mixing at a higher temperature during production. As the construction phase's energy contribution to the LCA is very small (as seen in Figure 18) these increases do not affect the net energy saving of 1.39% (as seen in Figure 18).

- **Warm Mix Asphalt (WMA) Technology:**

WMA technology decreases the energy consumption of the production phase as the WMA additive makes it possible for the bitumen to be heated to a lower temperature before it is able to mix with the aggregate. Less heat is thus required from the burner flame. This reduces the consumption of heavy fuel oil (HFO) and light burner fuel (LBF). These are fossil fuels which releases harmful CO_2 gasses into the atmosphere. WMA technology reduces the required compaction temperature and improves the workability of the asphalt. The asphalt can thus be compacted easier and this reduces the use of rollers. Rollers are driven by diesel combustion which is also a fossil fuel. The energy savings in the construction phase is small in comparison to the savings in the production phase but it must be remembered that a lower compaction temperature reduces the fumes on site which reduces the health risk for the labourers (as discussed in Chapter 2).

- **Combined RA and WMA technology:**

Table 34 shows the combined RA and WMA technology mix and the reference HMA mix.

Table 34: Combined Technology Energy Savings

Phase	HMA reference	WMA with 40% RA	Energy savings	Responsible technology
Material procurement	339.97	236.18	30.53%	RA
Transportation	285.83	271.86	4.89%	RA
Asphalt production	375.41	300.32	20.00%	WMA
Asphalt construction	2.83	2.70	4.79%	WMA
Service life	579.00	579.00	0.00%	
Total energy consumption (MJ/ton)	**1583.04**	**1390.06**	12.19%	RA + WMA

As RA technology is beneficial to the procurement and the transportation phase and WMA technology is beneficial to the production and the construction phase the energy savings that is achieved is noticeably high. The use of the WMA additive also acts as a rejuvenator to the RA and this allows a RA content of up to 40% in the mix which reduces the energy consumption further.

The final conclusions are provided in the following section.

5.6 Conclusion

The life cycle analysis (LCA) that was selected proved to be very efficient in determining the effects of new technology in the asphalt industry. The interaction with the asphalt manufacturer that was working on the N1 project provided good insight in how the production process works. It also shows that the South African asphalt industry is capable of this technology integration as this analysis was based on a current project in South Africa.

The results showed that an energy savings of 1.39% was achieved when only the RA technology was applied and a 4.65% saving was achieved when only the WMA technology was applied. It may thus be concluded that the WMA technology causes more energy savings than the RA technology. The WMA mix with 40% RA reduced the energy usage by 12.19% from the conventional HMA. It was also found that the combined use of these two technologies is beneficial as they both benefit different life cycle phases (Which increase the cumulative energy savings). It must also be noted that most of this energy savings is made up of fossil fuels that are non-renewable resources. RA also reduces the extraction of minerals from the earth by recycling old unusable material. A reduction in fossil fuel usage and mineral extraction is thus also achieved by using these technologies.

This analysis can be seen as motivation for the further integration of these technologies. Clients and engineers have certain criteria to look at when asphalt is designed for a project. The main decision making criteria include the cost and quality efficiency of the asphalt which in the past was seen as more important than the impact on the environment. In a modern world where natural resources are becoming limited it is important for engineers and designers to consider these technologies. This can thus be used as a decision making mechanism.

The next chapter investigates the cost comparison between the mix models that apply RA and WMA technologies.

CHAPTER 6: COST BENEFIT

6.1 Introduction

Chapter 6 consists of the cost analysis that is based on the case study described in Chapter 4. The scope of the LCCA is described in Chapter 4 which includes the following components: Material procurement, transportation, asphalt production, construction, service life and end of life. The chapter also includes the quality assurance of the results where sensitivity analyses are done on certain significant components.

The aims of this chapter are the following:

- To procure sufficient data from the N1 project as well as from literature where needed.
- To identify additional costs for the use of these technologies which are not included in the scope defined in Chapter 4.
- To quantify the cost of the four mix models defined in Chapter 4.
- To identify the most significant components of the life cycle on which quality assurance measures can be applied.
- To discuss the results and to identify the cost benefits of the technologies as well as where (which components) these benefits are most apparent.

6.2 Costing Components of the Cost Analysis

The cost analysis is done on the scope that is defined in Chapter 4. In this defined scope the machines and equipment that are used to manage the asphalt (from procurement to end of life phase) are the same for conventional HMA and for HMA that uses the RA and WMA technologies (as described with Figure 9 in Chapter 4 these are considered as constant components). However when RA technology is used additional machines and equipment need to be acquired which are not necessary for conventional HMA. It is thus important to add these additional costs to the analysis as it may have an effect on the potential benefit of using RA (As described with Figure 9 in Chapter 4 this is now a variable component).

6.3 Data Procurement

The costing data and prices that are used in this analysis have been procured from the following sources:

- Prices were obtained from local suppliers.

- Prices were also obtained from the project itself, through communicating with the asphalt supplier as well as the main contractor on the site. The asphalt supplier is National Asphalt and the management members that were contacted are:
  - Chris Stander, a director of National Asphalt.
  - Wynand Nortjè, technical manager of National Asphalt.
- Some RA statistics were obtained by interviewing Sabita member, Deon Pagel.

These people were contacted and interviewed via e-mail. The relevant e-mail correspondence is available in Appendix G.

All the prices are thus locally obtained which makes this cost analysis specifically focussed on the South African asphalt industry. The unit that the costing is measured in is the South African Rand (R).

The following paragraphs provide the LCCA which is done on the N1 project described in Chapter 4. Significant cost components will also be identified that will undergo sensitivity analysis to ensure the quality of the results. Some of the price values vary because of unique project conditions.

6.4 Cost Demands

The following sections calculate the cost demand of the HMA phases (analysis boundaries) that were defined in Chapter 4, namely: Material procurement, transportation, asphalt production, construction, service life and end of life. This chapter also includes the cost demand of the additional equipment required to use RA technology.

6.4.1 Material Procurement

The costs of aggregate, bitumen, WMA additive (Sasowax) and lime are shown in Table 35. These values also include the transportation cost to the plant. The transportation distances are the distance from the material supplier to the asphalt plant (These distances are given in Table 16 in Chapter 5). The rates below are the prices that are used on the N1 project. These are the rates obtained from the asphalt supplier, National Asphalt (Stander, 2013).

Table 35: Material Procurement Costs

Material	**Cost (R/ton)**	**Supplier**
Aggregate	R 140.00	Stone and Allied (Carletonville)
Bitumen	R 7,010.35	Shell (Durban)
WMA additive (Sasowax)	R 23,528.69	Sasol (Sasolburg)
Lime	R 1,871.21	Lime Distributors (Vereeniging)

Figure 19 shows the procurement process of RA. This process was discussed in Section 5.3.1 in Chapter 5

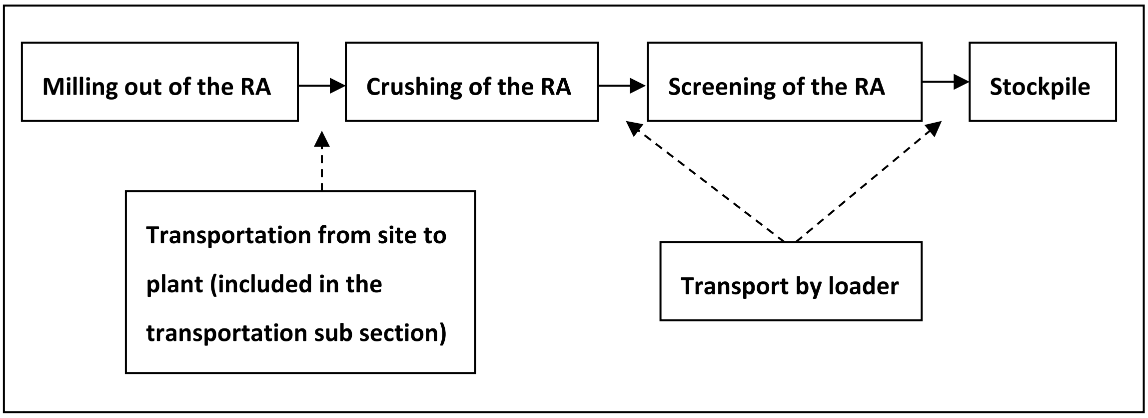

Figure 19: RA Procurement Phases

The following paragraphs discuss the different equipment used to complete the RA procurement process.

- ***Milling of RA***: The Wirtgen W2000 milling machine is used on the N1 project to mill out the RA. The milling capacity was obtained from the asphalt supplier, National Asphalt. The diesel consumption was obtained from the Wirtgen W2000 catalogue (Wirtgen Group, 2010). The price of diesel that is used was obtained from the Automobile Association (AA) on the 3rd of April 2013 (The Automobile Association (AA), 2013).
- ***Crushing of RA, Screening of RA and extra Loader***: The Terex impact crusher is used to crush the RA on the N1 project and a Terex Finlay 683 screening plant is used for the screening. An extra loader (CAT 928) is required to transport the RA at the plant. The diesel consumption as well as the crushing capacity was obtained from National Asphalt (Stander, 2013).

Table 36 shows the calculations of the cost of the RA procurement. These calculations exclude the cost calculation of the RA's transportation from the site to the asphalt plant.

Table 36: Cost of RA Procurement

Nr.	**Variable**	**Value**	**Source or calculation**
	Milling of RA (Wirtgen W2000)		
1	Milling capacity (ton/h)	471.75	(Stander, 2013)
2	Diesel Consumption (L/h)	56	(Wirtgen Group, 2010)
3	Diesel Consumption (L/ton)	0.12	2 ÷ 1
4	Diesel price (R/L)	R 12.02	(The Automobile Association (AA), 2013)
5	Milling cost demand (R/ton)	R 1.43	3 × 4

Table 36: Cost of RA Procurement (continues)			
Crushing of the RA (Terex impact crusher)			
Nr.	**Variable**	**Value**	**Source or calculation**
6	Diesel consumption (L/h)	34	(Stander, 2013)
7	Crushing capacity (ton/h)	150	(Stander, 2013)
8	Diesel consumption (L/ton)	0.23	6 ÷ 7
9	Diesel price (R/L)	R 12.02	(The Automobile Association (AA), 2013)
10	Crushing cost demand (R/ton)	R 2.72	8 × 9
Screening of RA (Terex Finlay 683)			
11	Diesel consumption (L/h)	15	(Stander, 2013)
12	Crushing capacity (ton/h)	150	(Stander, 2013)
13	Diesel consumption (L/ton)	0.1	11 ÷ 12
14	Diesel price (R/L)	R 12.02	(The Automobile Association (AA), 2013)
15	Crushing cost demand (R/ton)	R 1.20	13 × 14
	Loader required for RA screening and stockpiling (CAT 928)		
16	Diesel consumption (L/h)	15	(Stander, 2013)
17	Crushing capacity (ton/h)	150	(Stander, 2013)
18	Diesel consumption (L/ton)	0.1	16 ÷ 17
19	Diesel price (R/L)	R 12.02	(The Automobile Association (AA), 2013)
20	Crushing cost demand (R/ton)	R 1.20	18 × 19
21	**Total RA cost demand (R/ton)**	**R 6.56**	**5 + 10 + 15 + 20**

6.4.2 Transportation

The transportation cost of the following materials is included in their procurement prices:

- Aggregate
- Bitumen
- Lime
- WMA additive(Sasowax)

The transportation of the RA as well as the asphalt still need to be added. Table 37 shows the calculations of this transportation. The same distances were used as for the environmental analysis (These distances are given in Table 16 in Chapter 5). The price of diesel that is used was obtained from the Automobile Association (AA) on the 3rd of April 2013 (The Automobile Association (AA), 2013).

It has to be noted that a load is one truck and that the distance for one load includes the return trip of the truck as well. The diesel consumption is also an average between the full and the empty load diesel consumption. The equation used to calculate the cost demands in row 6 is: *(((1 ÷ 2) ÷ 3) × 5*

	Table 37: Transportation Costs		
Nr.	**Variable**	**RA from the project site to plant**	**New asphalt from plant to site**
1	**Distance for one load (km)**	40	40
2	**Diesel consumption (km/l)**	2	2
3	**Load capacity (tons)**	13	13
4	**Diesel consumption (L/ton)**	1.54	1.54
5	**Diesel price (R/L)**	R 12.02	R 12.02
6	**Total cost demand (R/ton)**	**R 18.49**	**R 18.49**

6.4.3 Asphalt Production

As described in Chapter 4 the asphalt production process has three energy components which are also seen as three costing components. They are the use of light burning fuel (LBF), heavy fuel oil (HFO) and electricity. Table 38 shows the cost per ton of asphalt for LBF and HFO consumption. The LBF is used to fuel the flame that keeps the bitumen at the right temperature (160°C) throughout the project and the HFO is used to fuel the burner flame in the plants mixing drum to dry and heat the aggregate. The same assumptions that were made in Chapter 4 were made to determine the LBF consumption. The plant production rate, the HFO consumption (L/ton) as well as the LBF and HFO prices were obtained from the asphalt supplier, National Asphalt (Stander, 2013).

	Table 38: LBF and HFO Costs		
Nr.	**Variable**	**Value**	**Source or calculation**
	Light Burning Fuel (LBF)		
1	Monthly consumption (L)	7500	(Stander, 2013)
2	Daily production time (hours)	10	Assumed
3	Number of production days a month	26	Assumed
4	Plant production rate (ton/hour)	100	(Stander, 2013)
5	LBF consumption (L/ton)	0.29	(1 ÷ (2 × 3)) ÷ 4
6	Price of LBF (R/L)	R 8.82	(Stander, 2013)
7	Cost of LBF (R/ton)	R 2.54	5 × 6
	Heavy Fuel Oil (HFO)		
8	HFO consumption (L/ton)	8	(Stander, 2013)
9	Price of HFO (R/L)	R 8.82	(Stander, 2013)

Table 38: LBF and HFO Costs (Continues)			
Nr.	**Variable**	**Value**	**Source or calculation**
10	Cost of HFO (R/ton)	R 70.56	8 × 9
11	**Total Cost (R/ton)**	**R 73.10**	**7 + 10**

The electricity costs of the asphalt production calculations is based on the electricity bill of National Asphalt for March 2013 for the Vanderbijlpark plant that is used on this project. The bill is available in Appendix G-2. According to the bill the following factors are used to compile the bill:

- ***Low season standard energy charge, low season peak energy charge and low season off peak energy charge:*** These are the three different tariffs for electricity usage in the plant's area. Low season means that it is between September and May when electricity is less expensive as the demand is less. The low season is used as the available bill for this study is measured on the low season and the price variance between low season and high season will be applicable for all the mix models. The impact of the technology on electricity consumption can thus be determined with either peak or low season rates. By looking at the Vanderbijl plant's bill in Appendix E-2 for March the distribution of electricity usage between these different tariffs are: Standard (54%), peak (19%) and off peak (27%). Table 39 shows the energy consumption of the asphalt plant for March 2013 as well as in which consumption bracket (off peak, standard and peak) it falls. The distribution is shown as a percentage of the total energy consumption found on the bill. This distribution is used in step 1 of the electricity cost calculations in Table 40.

Table 39: Electricity Distribution		
Energy consumption off peak (kWh)	6835.53	27%
Energy consumption standard (kWh)	13427.39	54%
Energy consumption peak (kWh)	4824.84	19%
Total energy consumed from electricity in March 2013	25087.76	100%

- ***Electrification and rural subsidy as well as retail environmental levy charge:*** these two charges each have a tariff for the total electricity usage as seen on the electricity bill.
- ***Network access charge and service charge:*** For these charges it was assumed for the purpose of these calculations that the network access and the service charges are calculated as a percentage of the above two charges. By looking at the bill it was calculated that the network access charge is an additional 38% cost of the combined costs of the two costs mentioned above. The service charge is an additional 8% of the two costs mentioned above.

The electricity energy demand was determined in Chapter 4 to be 45.05 MJ/ton of asphalt. This gives a total electricity energy demand of 331678.1 MJ (Based on the experimental tonnage of 7362.5

tons). The unit that the electricity is billed in is kilowatt per hour (kWh). The energy value must thus be converted to kWh. According to the Massachusetts Institute of Technology (MIT) 3.6 MJ is the equivalent of 1 kWh (Supple, 2007). The amount of kWh required for the asphalt production process is thus 92130.77 kWh. Table 41 shows the calculations of the total electricity cost of the asphalt production process. All the tariffs used in Table 40 were obtained from the Eskom bill that is attached in Appendix G-2.

Table 40: Asphalt Production Electricity Costs

	Electricity Component	Tariff (R/kWh)	Usage (kWh)	Cost
	Low Season Standard Energy Charge (54%)	R 0.4667	49750.62	R 23,218.61
	Low Season Peak Energy Charge (19 %)	R 0.7021	17504.85	R 12,290.15
	Low Season Off Peak Energy Charge (27%)	R 0.2595	24875.31	R 6,455.14
1	**Total**		92130.77	**R 41,963.91**
	Electrification and Rural Subsidy	R 0.0457	92130.77	R 4,210.38
	Retail Environmental levy charge	R 0.0350	92130.77	R 3,224.58
2	**Total**			**R 7,434.95**
	Network Access Charge	38% of (1+2)		R 18,771.57
	Service Charge	8% of (1+2)		R 3,951.91
3	**Total**			**R 22,723.48**
				R 72,122.34
	VAT	14%		R 10,097.13
4	**Total**			**R 82,219.47**
5	Total tonnage for the analysis = 7362.25 tons			
	Total cost of electricity (R/ton)	**4 ÷ 5**		**R 11.17**

6.4.4 Construction

This section quantifies the cost demand of the laying of the asphalt as well as the compaction of the asphalt.

a. Laying of the Asphalt

The asphalt on the N1 project is laid by the Voegele 1800-2 paver. The diesel consumption and speed was obtained from the paver's catalogue (Joseph Voegele AG, 2011) and the asphalt supplier, National Asphalt (Stander, 2013). It is again assumed that the paver and the rollers are static (not utilised) for an additional 10% of their running time. This assumption is made to improve the accuracy of the calculation. It is however not necessary to conduct a sensitivity analysis on this percentage as it will have little to no effect on the results as the cost demand of the paver and the rollers is very low. The price of diesel that is used was obtained from the Automobile Association (AA) on the 3rd of April 2013 (The Automobile Association (AA), 2013).

Table 41 shows the cost of paving on the N1 project.

	Table 41: Asphalt Laying Costs		
Nr.	**Variable**	**Value**	**Source or calculation**
	Voegele 1800-2 Paver		
1	Diesel consumption (L/h)	30	(Joseph Voegele AG, 2011)
2	Rolling speed (km/h)	0.84	(Joseph Voegele AG, 2011)
3	Distance of the lane(km)	10	
4	Diesel consumption(L)	357.14	(1 ÷ 2) × 3
5	10% of the fuel added for a non-utilised paver	392.86	1.1 × 4
6	Price of diesel (R/L)	R 12.02	(The Automobile Association (AA), 2013)
7	Total paving costs (R)	R 4,722.14	5 × 6
8	Total tonnage for the analysis (ton)	7362.45	
9	**Total cost (R/ton)**	**R 0.64**	**7 ÷ 8**

b. Compaction of the Asphalt

The asphalt compaction process uses three different types of rollers. The rolling speed, diesel consumption and the number of passes were obtained from the asphalt supplier, National Asphalt (Stander, 2013). The compaction cost is shown in Table 42.

Table 42: Asphalt Compaction Cost			
Nr.	**Variable**	**Value**	**Source or calculation**
	Steel Wheeled Rollers		
1	Diesel consumption (L/h)	8	(Stander, 2013)
2	Rolling speed (km/h)	5	(Stander, 2013)
3	Distance of the lane (km)	10	
4	Total number of passes by the roller	4	(Stander, 2013)
5	Total distance covered by this roller (km)	40	3 × 4
6	Total diesel consumption(L)	64	(1 ÷ 2) × 5
7	Price of diesel (R/L)	R 12.02	(The Automobile Association (AA), 2013)
8	Steel Wheeled Roller costs (Rand)	R 769.28	6 × 7

Table 42: Asphalt Compaction Cost (continues)			
	Pneumatic Rollers		
Nr.	**Variable**	**Value**	**Source or calculation**
9	Diesel consumption (L/h)	8	(Stander, 2013)
10	Rolling speed (km/h)	6	(Stander, 2013)
11	Distance of the lane (km)	10	
12	Total number of passes by the roller	4	(Stander, 2013)
13	Total distance covered by this roller (km)	40	11 × 12
14	Total diesel consumption(L)	53.33	(9 ÷ 10) × 13
15	Price of diesel (R/L)	R 12.02	(The Automobile Association (AA), 2013)
16	Steel Wheeled Roller costs (Rand)	R 641.07	14 × 15
	Three Point Rollers		
17	Diesel consumption (L/h)	7	(Stander, 2013)
18	Rolling speed (km/h)	6	(Stander, 2013)
19	Distance of the lane (km)	10	
20	Total number of passes by the roller	3	(Stander, 2013)
21	Total distance covered by this roller (km)	30	19 × 20
22	Total diesel consumption(L)	35	(17 ÷ 18) × 21
23	Price of diesel (R/L)	R 12.02	(The Automobile Association (AA), 2013)
24	Steel Wheeled Roller costs (Rand)	R 420.70	22 × 23
25	Total cost:	R 1831.05	8 + 16 + 24
26	10% of the fuel added for a non-utilised paver	R 2014.15	25 × 1.1
27	Total tonnage for the analysis (ton)	7362.45	
28	**Total cost (R/ton)**	**R 0.27**	**26 ÷ 27**

6.4.5 Service Life

As discussed in Chapter 5 the pavement structure will be maintained during its 15 year life span by milling out the existing UTFC surface layer and replacing it with a new UTFC layer. This maintenance will occur after 7 years (see Figure 11). By again looking at the study by (Collings & Jenkins, 2009) the corresponding cost of the selected maintenance was obtained. Table 43 shows the calculations that were necessary to obtain the cost per ton of asphalt for the service life phase. The study by (Collings & Jenkins, 2009) used discount rates of 4%, 6% and 8%. It was decided to use a discount rate of 8%. The Present Worth of Costs (PWOC) is calculated for the period of 7 years to determine the present cost per ton for the maintenance. The equation used for the PWOC calculation can be found in the Technical Recommendations for Highways (TRH4) (Committee of Land Transport Officials (COLTO), 1996). A value of R439.95 per ton is thus used for the cost of the service life phase.

Table 43: Cost of the Service Life		
Variables		**Source**
Mill and Replace energy demand for 10 000m² (R)	R 754,000.00	(Collings & Jenkins, 2009)
Milling depth (m)	0.04	
Asphalt density of the N1 project (kg/m³)	2500	assumed
Period until maintenance (years)	7	
Discount rate (%)	8	(Committee of Land Transport Officials (COLTO), 1996)
Present Worth of Costs (PWOC) (R/ton)	**R 439.95**	

6.4.6 End of Life

The end of life phase has already been discussed in Section 5.3.6. The same principle is applied to the LCCA and thus no extra cost will be added in the end of life phase (as in the LCA) as cost for the recycling process has already been added in other phases of the LCCA (Procurement and transportation phase).

6.4.7 Additional Costs of the Technologies

The use of RA and WMA technology is new and thus require certain modifications to the plant to enable the production of this asphalt. The WMA technology that is used in this study requires no additional plant or process costs (Sasowax 1655 which is mixed into the bitumen tank). The RA does however require a few plant and process modifications. These are modifications that are not necessary to produce normal HMA and can thus be seen as an additional technology cost. These modifications are listed below (Appendix G-3) (Stander, 2013):

- An impact crusher is needed that breaks the RA into smaller sizes.
- A screening plant is required that screens the RA into the correct gradations.
- An extra loader is used to transport the RA between crushing, screening and the RA bins.
- The plant must be modified to be able to mix the RA into the asphalt. The modifications that were made by the Vanderbijlpark plant to use 40 % RA are: A new heating and mixing drum was added, including wet scrubbers and RA bins.

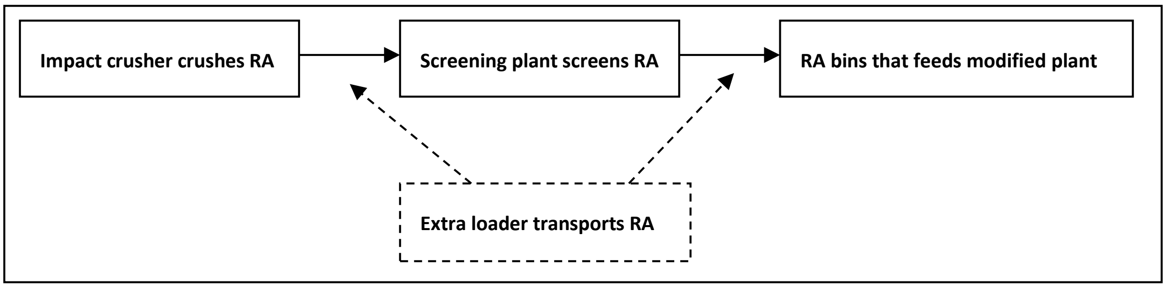

Figure 20: RA Process

The prices of these additional costs are a once of payment. The costs of each of these components are listed in Table 44. They were obtained from the asphalt supplier, National Asphalt (Stander, 2013). The e-mail correspondences as well as the quotations for the impact crusher and screening plant are attached in Appendix G-4 and G-5.

Table 44: Additional Costs of the Vanderbijlpark Plant		
Terex Impact crusher	R 3,385,800.00	Appendix G-4
Mobile screening plant	R 1,972,200.00	Appendix G-5
CAT 928H loader	R 1,500,000.00	(Stander, 2013)
Plant modifications	R 7,000,000.00	(Stander, 2013)

The LCCA is quantified in Rand/ton. These once off modification costs thus have to be converted to Rand/ton. In order to do this it is required to know how many tons will be produced by these modifications in their life time. It was thus decided to make a prediction of how much asphalt these modifications will produce through their life time. To make this prediction as accurate as possible known variables were included into the calculation as well as some assumed variables.

According to Chris Stander at National Asphalt (Stander, 2013) they estimate an asphalt production of 960000 tons for 2014. At the moment they have a total of four plants that can produce asphalt with RA (Stander, 2013). These conversations are also available in Appendix G-6 and G-7. The following variables were identified to improve the accuracy of the prediction.

- Life expectancy of the modifications (service life).
- The asphalt production growth rate of National Asphalt.
- The average RA content that is specified when a mix contains RA in South Africa.
- The percentage of the total yearly asphalt mixes in South Africa that is specified to include RA.
- Number of plants capable of processing RA.

Table 45 shows the values of the variables that were obtained through discussions with Deon Pagel (Sabita) (Pagel, 2013) and Chris Stander (National Asphalt) (Stander, 2013). As no specific statistics on these variables are available the values in Table 45 was estimated and predicted by them. A sensitivity analysis is also performed in Section 6.5 to show the effect of the varying values. This combination of practical knowledge and a sensitivity analysis helps to make an informed prediction on the life time production of these additional costs which is seen as sufficient for this study.

Table 45: Additional Cost Variables		
Variables	**Practitioners prediction**	**Variation for sensitivity analysis**
Life expectancy of the plant machines and components.	10 - 15 Years	10 – 15 years
Asphalt production yearly growth rate	5%	5%
The average RA content that is specified when a mix contains RA in South Africa.	20%	20% - 40%
The percentage of the total yearly asphalt mixes in South Africa that is specified to include RA.	Currently 10% but will increase to 15% – 20% before long	10% – 20%
Number of plants capable of processing RA.	Currently 4	Very unpredictable

A. *Calculation Methodology*

Table 46 lists and describes the variables that were used in the calculations of the additional costs.

Table 46: Additional Costs Calculation Variables	
Symbol	**Description**
A	Initial annual asphalt production for National Asphalt.
B	Percentage of asphalt mixes that are specified to contain RA.
C	Amount of asphalt mixes that contains RA.
D	Average percentage RA specified in mixes that contains RA.
RA_t	Total initial annual RA handled by National Asphalt.
F	Number of National Asphalt plants that can process RA.
RA_1	Annual amount of RA processed by one plant.
i	The annual growth rate of the asphalt production of National Asphalt.
n	The life expectancy of the plant machine or component in years.
RA_n	The total RA processed by the plant machine or component by the specific life time n.
M	Material processed by each machine or component.
Pi	Purchase price of each plant machine or component.
T	The cost of the plant machine or component per ton of asphalt.

Step 1:

The first step is to calculate the amount of mixes that include RA that are produced by National Asphalt annually. This is thus the amount of mixes that actually uses the RA technology.

$$\boldsymbol{C = A \times B}$$

Step 2:

As the screening plant, extra loader and impact crusher only processes the RA it is important to know what percentage of the RA mixes is actually RA (mixes is made up of RA, aggregate, bitumen and filler). The total amount of RA processed by National Asphalt annually is thus calculated.

$$\boldsymbol{RA_t = C \times D}$$

Step 3:

As each plant that processes RA requires these additional machines the RA processing of a single plant is used.

$$RA_1 = RA_t \div F$$

Step 4:

The initial annual amount of RA that is processed is now known. The total life time usage (RA processing) of the machines is now calculated by integrating the annual growth rate as well as the life expectancy.

$$RA_n = RA_1 \times (1 + i)^n$$

Step 5:

In this step the final amount of material processed by each component in their life time is calculated. Table 47 shows the summary of the processed materials. It must be noted that the screening plant, the impact crusher and the loader processes less material than the plant modifications as the plant modifications processes the entire mix through the plant where the other three only processes the RA (Which is a percentage of 10 – 40 percent of the entire mix).

Table 47: Material Processed	
Plant Machine or Component	**Material Processed**
Screening plant	RA
Impact crusher	RA
Extra loader	RA
Plant modifications	The whole mix including the other aggregate and bitumen.

Step 6:

In this step the final price of each machine or component is calculated per ton of material processed.

$$T = P \div M$$

B. Results

Table 48 shows the results of the additional costs calculation. These results were obtained before doing a sensitivity analysis. These values were calculated by assuming the following:

- The life expectancy predicted by the practitioners is between 10 and 15 years. The life expectancy of the plant modifications is thus assumed to be 10 years as it processes much more material than the other three (screening plant, extra loader and impact crusher). The other three's life expectancy was estimated at 15 years.
- The yearly growth was assumed to be 5% as the practitioners predicted. This value can vary because of market related factors that will not be discussed in this study.
- The amount of mixes that contain RA in South Africa was taken to be 10% of total annual asphalt production as predicted by the practitioners.
- The average RA content in these mixes was taken as 20%.
- The current amount of asphalt plants that can produce RA mixes for National Asphalt is four. However, a number of six were used as it is likely that with the predicted increase of RA usage, National Asphalt will include more RA plants to their arsenal.

It must be remembered that a sensitivity analysis is done in Section 6.5 to investigate the impact of these variations.

Table 48 shows the results obtained from these calculations.

Table 48: Additional Costs

Modification	Cost (Rand/ton)	Material Worked
Terex Impact crusher	R 38.92	RA
Mobile screening plant	R 22.67	RA
CAT 928H loader	R 17.24	RA
Plant modifications	R 27.61	Asphalt

6.5 Results Quality Assurance

The input values used in the LCCA was obtained from the specific project data from the N1 project and is thus project specific. This section conducts sensitivity analyses to find out if varying input values have an effect on the final cost of the LCCA. It is important to conduct these sensitivity analyses to investigate if the cost rank of the different mix models change when the input values vary. A change in the rank of the final costs shows that the varying input values has an effect of the impact of the technologies on the LCCA. Verifying other values in the analysis also makes this LCCA more universal and not only project specific.

It was decided to list all the contributing factors (as in Chapter 5) and to show their cost contribution to the final asphalt life cycle cost. It was then decided as in Chapter 5 to select the top five contributors and conduct sensitivity analyses on these factors. The varying input values that are used in the sensitivity analyses are obtained from asphalt suppliers.

The four mix models that are analysed are the following:

- HMA Reference,
- HMA with 20% RA,
- WMA with 0% RA,
- WMA with 40% RA.

Table 49 shows the cost contribution of the contributing factors for two of the mix models. The five highest contributors are highlighted.

Table 49: Cost Contributions

Contributing Factors	WMA with 40% RA		HMA reference	
	Total Cost (R)	Contribution (%)	Total Cost (R)	Contribution (%)
Aggregate	R 587 523.11	9.23%	R 979 205.19	13.6%
Virgin Bitumen	R 1 135 492.96	17.84%	R 2 064 532.65	28.7%
Lime	R 137 766.81	2.16%	R 137 766.81	1.9%
Reclaimed Asphalt (RA)	R 48 504.03	0.76%	R 0.00	0.0%
WMA additive	R 18 340.21	0.29%	R 0.00	0.0%
Transport	R 187 885.07	2.95%	R 136 148.60	1.9%
HFO	R 415 595.58	6.53%	R 519 494.47	7.2%
LBF	R 14 960.50	0.23%	R 18 700.62	0.3%
electricity	R 65 775.53	1.03%	R 82 219.41	1.1%
Asphalt Paving	R 4 722.14	0.07%	R 4 722.14	0.1%
Asphalt Compaction	R 2 416.98	0.04%	R 3 021.22	0.0%
Additional technology costs	R 508 526.40	7.99%	R 0.00	0.0%
Service Life	R 3 239 107.68	50.88%	R 3 239 107.68	45.1%
	R 6 366 616.98	100.00%	**R 7 184 918.79**	100.0%

It must be noted that the service life contribution is the most but as the service life contribution is the same for all four of the mix models it is not taken into consideration for the sensitivity analysis. A variation in this value will not affect the relationship between the mix models' total cost apart from increasing or decreasing them in the same way.

The top five contributors are thus:

- Aggregate,
- Virgin bitumen,
- Transport,

- Heavy fuel oil (HFO),
- Additional technology costs.

Sensitivity analyses are performed on each of these factors.

A. Aggregate

The aggregate price that was obtained for the N1 project was R140 per ton with delivery included. National asphalt was again asked what the variation is in aggregate prices. National asphalt's asphalt plants are spread across five of the nine provinces in South Africa. They must thus make use of different sources of aggregate. According to them the price of aggregate varies between R140 and R355 per ton with delivery included (Stander, 2013). Figure 21 shows the cost sensitivity analysis.

Figure 21: Aggregate LCCA Sensitivity Analysis

Figure 21 show that the varying aggregate prices do not have an impact on the rank of the mix models' total cost and it does thus not affect the impact the technologies have on the mix models. It can however be noted as the aggregate price increases that the mixes with RA become more cost effective as less aggregate is required in those mixes.

B. Virgin bitumen

The bitumen whole sale list prices were obtained from National Asphalt which includes prices from suppliers in South Africa (the price list is available in Appendix G-8), they are: Shell, Engen, Masana (BP), Sasol, Tosas (SA), Total (SA) and Caltex. These prices include the following grades of bitumen:

40/50, 60/70 and 80/100. The prices for the 12th of September was used and it ranged between R6 167 per ton and R8573 per ton which includes transport. These values were used to conduct the cost sensitivity analysis shown in Figure 22.

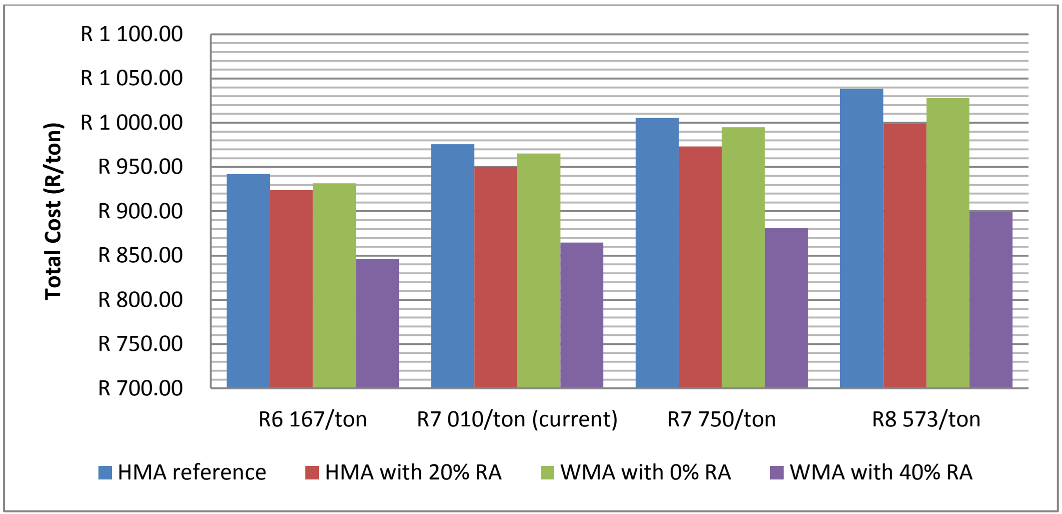

Figure 22: Virgin Bitumen LCCA Sensitivity Analysis

Figure 22 shows that the varying bitumen price does not change the rank of the mix models' total cost. However, it can again be seen that the RA mixes (as in the aggregate analysis) become more cost effective with a higher price as they use less bitumen.

C. Transport

The transportation of the aggregate, bitumen, lime and WMA additive are all included in their procurement prices. The transportation cost that was calculated in the LCCA was the transportation of the RA from where it was milled out of the pavement and the transportation of the new asphalt from the plant to the site. These two factors thus have the same distance. The distance from the plant to the paving site on the N1 project is 20km. This distance cannot become too far as the asphalt cools down and become difficult to compact. A maximum distance of 100km is thus selected for the sensitivity analysis.

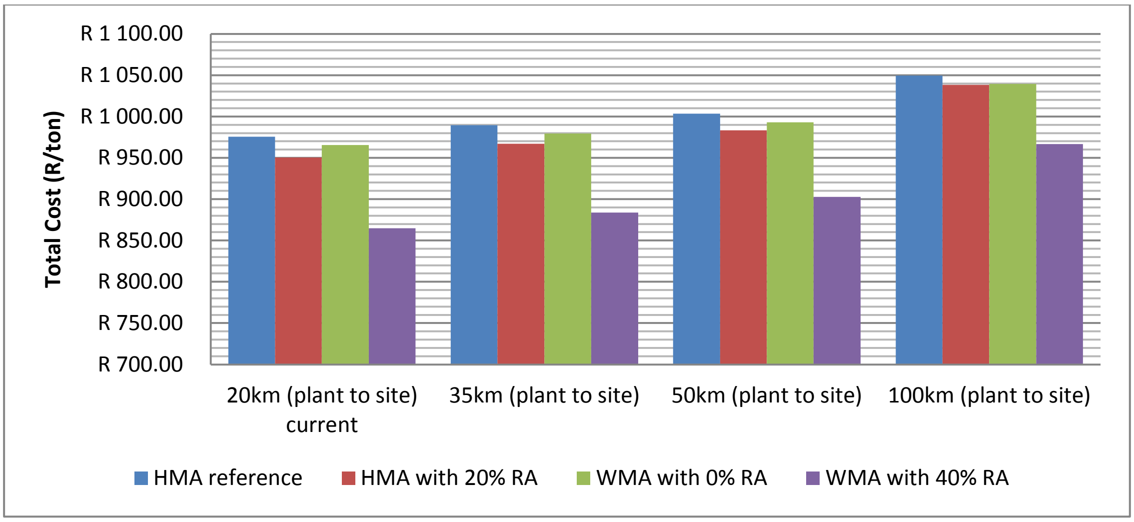

Figure 23: Transport LCCA Sensitivity Analysis

Figure 23 shows the effect that the increase in distance between the asphalt plant and the paving site has on the mix models. These varying values do not affect the rank of the mix models' total cost but it is noticeable that the 20% RA mix's price increases as the distance increases. The reason for this is that the RA must be transported from the site back to the plant and this increases the transporting cost.

D. Heavy oil fuel (HFO)

The HFO usage variation of National Asphalt was used in Chapter 5 and is used in this analysis as well. The usage varies between 5.5 l/ton and 10 l/ton. Figure 23 shows the cost sensitivity analysis of HFO. (Stander, 2013)

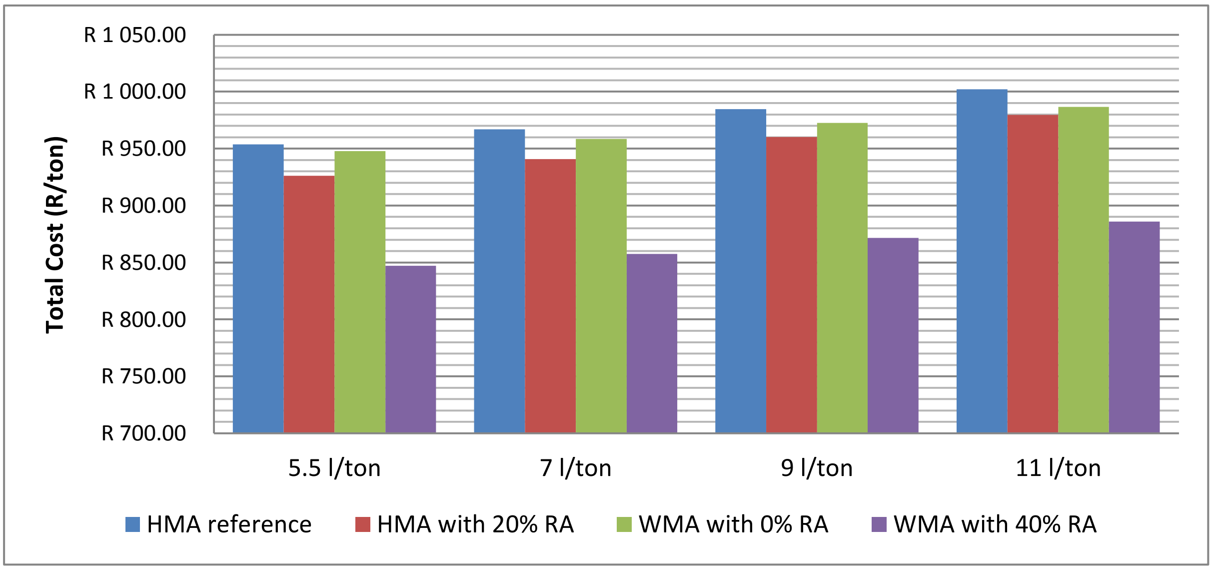

Figure 24: Heavy fuel oil LCCA Sensitivity Analysis

Figure 24 shows that the increase in HFO consumption does not affect the rank of the mix models' total cost and that the input value from the N1 project (8 l/ton) will be used in the LCCA.

E. Additional Costs of Technology

The following variables were identified in Section 6.4.7 as the contributing factors to the determination of the additional cost of the technology.

- Life expectancy of the modifications (service life).
- The asphalt production growth rate of National Asphalt.
- The average RA content that is specified when a mix contains RA in South Africa.
- The percentage of the total yearly asphalt mixes in South Africa that is specified to include RA.
- Number of plants capable of processing RA.

The variances in Table 50 were identified from discussions with Deon Pagel (Sabita) (Pagel, 2013) and Chris Stander (National Asphalt) (Stander, 2013).

Table 50: Variances for Additional Technology Costs Variances

Variables	Practitioners prediction	Variation for sensitivity analysis
Life expectancy of the plant machines and components.	10 - 15 Years	10 – 15 years
Asphalt production yearly growth rate	5%	5%
The average RA content that is specified when a mix contains RA in South Africa.	20%	20% - 40%
The percentage of the total yearly asphalt mixes in South Africa that is specified to contain RA.	Currently 10% but will increase to 15% – 20% before long	10% – 20%
Number of plants capable of processing RA.	Currently 4	Very unpredictable

The yearly growth rate of National Asphalt's asphalt production is kept at 5% as this is recommended by the asphalt supplier (Stander, 2013). The number of plants is also kept at 6 as decided in the analysis (as the supplier will surely increase his RA mixing capacity with an increase of this technology). The varying factors are thus the following:

- Life expectancy of the plant machines and components.
- The average RA content that is specified when a mix contains RA in South Africa.
- The percentage of the total yearly asphalt mixes in South Africa that is specified to contain RA.

Table 51 shows the different options that have been selected to conduct a sensitivity analysis.

Table 51: Additional Technology Cost Variances for the Sensitivity Analysis			
	Life expectancy	**The average RA content that is specified when a mix contains RA in South Africa.**	**The percentage of the total yearly asphalt mixes in South Africa that is specified to contain RA.**
Current	15 years for the machines that only process RA and 10 years for the plant modifications that needs to process the whole mix.	20%	10%
Option 1	13 years for all the machines	30%	20%
Option 2	10 years for all the machines	40%	10%

Figure 25 shows the sensitivity analysis that is done on the options described in Table 51.

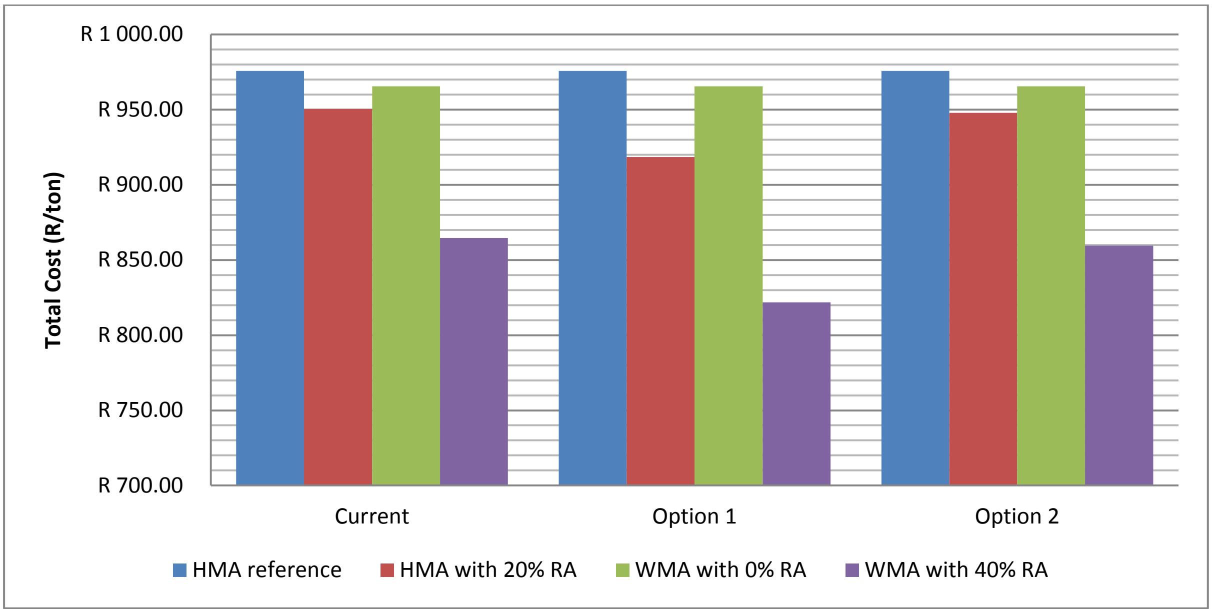

Figure 25: Additional Technology Cost Sensitivity Analysis

The option that is currently used in the analysis is a more conservative option than the other two options as the amount of material that is processed is the lowest in this option. The cost per ton is thus more. It is thus decided to use the values that are currently used as it is conservative and making predictions on the future use of the use of the RA technology is difficult.

<u>Sensitivity Analysis conclusion:</u>

The five highest cost contributors were identified and sensitivity analyses were conducted on them. Through these analyses it was determined if the values that are used in the LCCA are realistic and if a variance in these values changes the rank of the mix models' cost impact. The variance in the transportation distances affected the rank of the mix models and thus the impact of the technologies on the cost impact. It was thus decided to increase the distance between the asphalt plant and the paving site to make the results more realistic. The other four analyses showed increase cost values due to varying input values but did not affect the rank of the mix models cot impact.

Through these analyses the input values of the LCCA could be refined to produce the most accurate results. This also makes the LCCA more universal and allows it to be interpreted not just as a specific project but for a range of projects that fulfil the broad requirements of the case study. The final results of the LCCA are discussed in the next section.

6.6 Results and Discussions

Table 52 shows the cost comparison between the four mix models. The percentage cost savings that was achieved with regards to the HMA reference mix is also shown.

Table 52: Cost Savings from Using the Technologies

Mix Model	Total Cost (R/ton)	Cost savings from using the technologies
HMA reference	R 1,031.37	0.00%
HMA with 20% RA	R1,016.54	1.44%
WMA with 0% RA	R1,021.02	1.00%
WMA with 40% RA	R941.30	8.73%

Table 52 shows that all the technologies reduce the cost of the conventional HMA. It can be seen that the use of only RA technology reduces the cost of the asphalt more than using only the WMA technology. This was not the case in the life cycle analysis (LCA) where the WMA technology saves more energy than the RA technology. Once again it can be seen that the combination of the two technologies is the most cost effective and that it produces a cost saving of 8.73%.

Figure 25 shows the contributions of each phase to the total cost of the four mix models. The service life cost is again seen as a constant as all four the mix models undergoes the same rehabilitation option. The use of only RA technology (HMA with 20% RA mix), as in the LCA, benefits the procurement phase. It must be noted that the transportation costs of all the material are included in their procurement costs except for the transportation of the RA to the plant and the new asphalt to the site (these fall under transportation). It is thus assumed that the transportation phase is also benefited by the RA technology even though the transportation phase shows a higher cost than the reference HMA in Figure 25.

The use of only WMA technology (WMA with 0% RA mix) also benefits the production and construction phase as in the LCA. This cost impact is however smaller than the cost impact RA technology has on the mix models.

The use of RA technology requires additional costs to be able to use this technology. It was however found that these additional costs do not make the use of RA technology more expensive than the reference HMA mix. The cost savings in the procurement and transportation phase is thus significant enough to allow the HMA with 20% RA mix to still be more economical than the reference HMA.

Figure 26 also shows that the combined use of these two technologies is the most cost effective. These technologies complement each other in the sense that they benefit different phases in the asphalt life cycle.

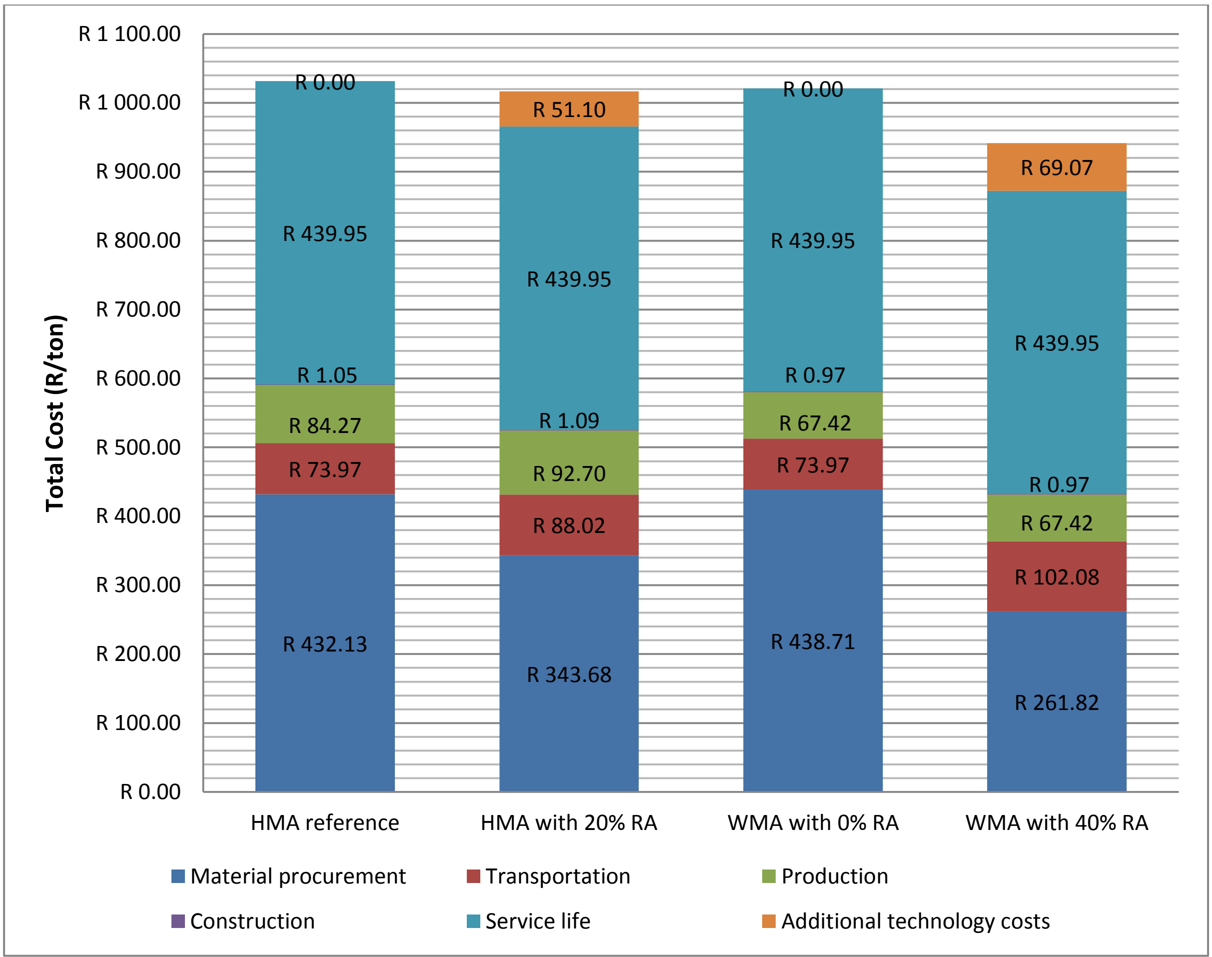

Figure 26: LCCA Cost Demand

The following is observed of each technology from the results obtained from the analysis:

- **Reclaimed Asphalt (RA) Technology:**

The use of this technology reduces the cost in the procurement and the transportation phase. This reduction is attributed to the recycling of old asphalt that contains residue bitumen and aggregate. The amount of virgin bitumen and aggregate that is required for the project is thus reduced. This reduces the haulage distances as less bitumen and aggregate needs to be procured. The high bitumen and aggregate prices also makes the use of RA technology more economical as a reduction in bitumen requirements reduces the cost savings even further.

- **Warm Mix Asphalt (WMA) Technology:**

The use of WMA technology reduces the production temperature of the asphalt and thus reduces the combustion of fossil fuels like heavy fuel oil (HFO) and light burner fuel (LBF). This reduces the cost of production as less HFO and LBF is required. The WMA additive also improves the workability of the asphalt and makes it easier to compact (As discussed in Chapter 2). The compaction effort that is required to reach the right asphalt density is thus reduced and fewer rollers are required. This reduces the diesel consumption of the compaction process and thus reduces the cost. The cost savings of the WMA technology is not as high as the RA technology as the high bitumen price inflates the cost impact of the RA technology.

- **Combined RA and WMA technology:**

Table 53 shows the cost comparison of the contributing phases of the HMA reference mix and the mix that uses both the technologies.

Table 53: Combined Technology Cost Savings

Phase	HMA reference	WMA with 40% RA	Cost savings	Technology responsible
Material procurement	R 432.13	R 261.82	39.41%	RA
Transportation	R 73.97	R 102.08	cost increase	
Production	R 84.27	R 67.42	20.00%	WMA
Construction	R 1.05	R 0.97	7.80%	RA
Service life	R 439.95	R 439.95	0.00%	
Additional technology costs	R 0.00	R 69.07	cost increase	
Total cost per ton	**R 1,031.37**	**R 941.30**	**8.73%**	**RA + WMA**

Table 53 also shows the cost savings achieved by each phase. The WMA technology has a 20% cost saving in the production phase. The use of the high RA content results in a large cost saving in the procurement phase (39.41%). As mentioned before this saving is attributed to the high bitumen and aggregate prices that increases the savings. It also shows how valuable the use of RA can be to authority in charge of the project as it can cause projects to be completed at a lower rate. A total saving of 8.73% by applying the RA and WMA technology again shows that using these two technologies together has a cost benefit of a noticeable proportion.

6.7 Conclusion

The life cycle cost analysis (LCCA) has proven to be a valuable tool to investigate the impact that the RA and WMA technologies have on a specific project. It is useful in the sense that the phases can be identified that is impacted by the technologies and the magnitude of these impacts can also be quantified. Through the interaction with asphalt suppliers and literature data was acquired to provide input values for the LCCA accurately. The LCCA was conducted on a case study and the initial data that was procured was project specific. Sensitivity analyses were then conducted on the five highest cost contributors. Asphalt suppliers and literature was then consulted to identify the variation that might occur in practice in other projects which was used in the sensitivity analyses. Through this some values (such as transport distances) was adjusted to make the results of the LCCA more universal.

The LCCA results showed that the individual use of both the technologies already reduces the cost of the mix models. The combined use of the technologies again complemented each other as they induced a cost saving of 8.73% (When compared to the reference HMA mix).

The environmental analysis and the cost analysis had some similarities in the sense that there is energy and cost savings that is induced by the application of the RA and WMA technologies. The following can thus be concluded:

- WMA technology used individually reduces the cost and energy demand of the asphalt (in comparison to the HMA reference mix which uses no technology).
- RA technology used individually reduces the cost and energy demand of the asphalt (in comparison to the HMA reference mix which uses no technology).
- However, WMA technology energy savings > RA technology energy savings.
- However, WMA technology cost savings < RA technology cost savings.
- The combined use of these technologies complements each other and further increases the energy and cost savings.

Chapter 7 compiles all the conclusions and findings that were made in this study. The risks and benefits are discussed to evaluate the integration of these technologies in a non-bias manner.

CHAPTER 7: TECHNOLOGY BENEFIT AND RISK DISCUSSION

7.1 Introduction

In Chapter 2 to Chapter 6 a systematic approach was used to identify the risks and benefits of RA and WMA technology as well as the magnitude of these benefits. This chapter discusses the findings that were made throughout the whole study. It also compares the risks, benefits and other findings that were made to make a final synthesis on the integration of these technologies in South Africa.

The aims of Chapter 7 are:

- To summarise and list the findings that were made throughout the study.
- To discuss the benefits and risks with regards to each other and to discuss the final verdict of the integration of these technologies in South Africa.

7.2 Benefit and Risk Discussion

The following section discusses the findings that were made throughout the study.

7.2.1 Benefit Investigation Summary

In Chapter 2 (literature review) the benefits of RA and WMA technologies were identified. These benefits were compared to the problems that were identified in the different HMA life cycle phases. 21 problem areas were identified of which the combined benefits of the technologies improved 14 of these problem areas. From literature it was found that the RA technology benefits the procurement phase and the end of life phase. It was also founded that WMA technology can benefit the production and construction phases. By combining these two technologies four of the five HMA life cycle phases can thus be potentially benefited. This was the first indication that these two technologies complement each other. Chapter 2 also concluded that the primary categories that the benefits occur in are the reduction in environmental and cost impact of HMA.

Chapter 2 also investigated prior research done in the field of quantifying environmental and cost impact. From the prior research it was decided to conduct a LCA (energy analysis) and a LCCA (cost analysis) to investigate and analyse the magnitude of these benefits in the South African asphalt industry. In Chapter 3 interviews were conducted with specialists in the field of these technologies. These interviews were used to verify the primary benefits of these technologies that were identified in the literature review. All nine of the specialists that were interviewed stated that the main benefits of these technologies are the environmental impact reduction and the cost savings. It was concluded that the main benefits are the environmental impact reduction and the cost savings. It was also decided to conduct a LCA and LCCA on a case study to determine the magnitude of these benefits and the specific phases where it occurs.

A South African project was selected as the case study to conduct the analyses on. The selected project was a Sanral project that is done on the N1. The case study was based on the life cycle of the BTB layer of the asphalt pavement. This layer was selected as it was specified to use a RA content of 40% and used a WMA technology called Sasowax 1655 (organic additive). This was thus appropriate as it applied a high RA content and a WMA technology (which is used together). The case study is limited to some of the project parameters (see Section 4.8). The LCA and LCCA were thus conducted on this project.

Four mix models were defined to make it possible to see the impact of each technology individually as well as collectively. They are:

- HMA, reference (None of the technologies),
- HMA with 20 % RA (Uses only RA technology),
- WMA with 0% RA (Uses only WMA technology),
- WMA with 40% RA (Uses both the technologies).

The results that were obtained are discussed below:

Table 54 shows the energy and cost savings that were obtained by applying the different technologies (In comparison to the HMA reference mix).

Table 54: Energy and Cost Saving

Mix Models	Total Cost (R/ton)	Cost savings from using the technologies	Total Energy Consumption (MJ/ton)	Energy savings from using technologies
HMA reference	R 1,031.37	0.00%	1583.04	0.00%
HMA with 20% RA	R 1,016.54	1.44%	1560.98	1.39%
WMA with 0% RA	R 1,021.02	1.00%	1509.39	4.65%
WMA with 40% RA	R 941.30	8.73%	1390.06	12.19%

It can be seen that both the technologies induce a cost and an energy saving. Proof is thus provided from three sources that these technologies reduce the cost and environmental impact. They are: Through literature, specialist interviews and LCA and LCCA results. It can also be seen that the combined use of these technologies reduce the environmental and cost impact even more. Proof is thus provided from two sources that these two technologies are most effective when they are used together. They are: Through literature and LCA and LCCA results. According to the results in Table 55 the reduction in the environmental impact is more than the cost savings of the technologies. The following was also observed from the LCA and LCCA results.

- WMA technology used individually reduces the cost and energy demand of the asphalt (in comparison to the HMA reference mix which uses no technology).
- RA technology used individually reduces the cost and energy demand of the asphalt (in comparison to the HMA reference mix which uses no technology).
- WMA technology energy savings (4.65%) > RA technology energy savings (1.39%).
- WMA technology cost savings (1.00%) < RA technology cost savings (1.44%).

It was also found through the results of the LCA and LCCA that the RA is beneficial to the procurement phase (which correlates with the findings in the literature review in Chapter 2). The large reduction in bitumen and aggregate requirements when using RA and the high bitumen and aggregate prices especially makes the cost saving high. It was found from the results of the LCA and LCCA that the WMA technology is beneficial to the production and construction phase (which correlates to the findings in the literature review in Chapter 2).

A total cost saving of 8.73% and an energy saving of 12.19% was obtained from the LCA and LCCA results. It must be remembered that these savings includes the preservation of natural resources and the reduction in the use of fossil fuels which further increases the environmental benefit.

The next section summarises the technology risks that were identified in this study.

7.2.2 Risk Investigation Summary

Risks were identified by interviewing specialists in the field of RA and WMA technology. Risks were identified in three phases of the life cycle phases of asphalt. These are: Design risks, production risks and construction risks respectively. Table 55 and Table 56 show the risks that were identified for the use of RA and WMA technology.

Table 55: WMA Technology risks		
Design Risks	**1**	Establishing the optimal technology among a number of options that would be conducive to the plant, site location and construction capability of the laying contractor. There are in excess of 20 different WMA technologies on the market with each product having its own advantages and limitations so it would be very difficult to specify WMA.
	2	Not presently specified in COLTO, so new WMA project specifications have to be drawn up.
Production Risks	**1**	The use of WMA technology is not specified in COLTO. The WMA technology dosages are sometimes still adjusted during the production phase (as a result of initial design faults) which has time and cost related risks.
	2	The plant must be able to run at lower temperature settings (up to 30°C) and if even temperature distribution in the drum at the lower temperature cannot be achieved then aggregate coating problems can arise.
	3	If the WMA technology is not properly implemented/added/mixed during production it could cause poor quality performance.
Construction Risks	**1**	WMA brings about a much larger compaction window and this can result in over compaction. WMA can be compacted at a lower temperature than HMA (as a result of the WMA additive). If WMA is compacted at the same temperature as HMA it compacts faster and may lead to over compaction.

Table 56: RA Technology risks		
Design Risks	**1**	If the client specifies a minimum RA percentage it puts a limit on the number of contractors that can bid on the project as there are limited asphalt plants in the country that can use more than 25% RA successfully.
	2	It needs to be understood by Client bodies and designers (engineers) that the higher the RA content that is specified, the more the RA need to be processed before use (More crushing and screening into different fractions).
	3	Lack of maintenance and control of the RA stockpiles.
	4	Making a realistic, stochastic analysis of the RA in stockpiles in terms of composition, moisture and binder qualities (where appropriate i.e. where higher RA content is contemplated). To determine optimum RA percentage in new mix.
	5	Not presently specified in COLTO, so new project specs have to be drawn up
	6	The specifying of RA on high risk projects with very high traffic needs to be considered with care. If the RA is not treated correctly premature failures could occur.

Table 56: RA Technology risks (Continues)		
Production Risks	1	RA introduction into the drum must be well managed in order to prevent burning of the RA's residue binder or further ageing of the binder.
	2	Fluctuation in binder content as a result of the high RA content (that contains residue binder).
	3	A lack of quality control: The particle size of the RA, the properties of the residue binder and foreign matter in the RA must be monitored as it is relevant to the quality of the asphalt mix.
	4	Using the correct amount of softer binder or rejuvenators in high RA content asphalt mixes to maintain a manageable workability.
	5	Lack of proper RA stockpile control that ensures that the different particle sizes are kept separate and dry.
	6	To low temperatures can lead to partial coating of the aggregate and moisture being trapped and then cause adhesion problems.
	7	Mixing plant capabilities. Incorrect production plant and systems.
Construction risks	1	In the normal sense RA poses no risk on the construction side but if a high RA contents is used in conjunction with a rejuvenator then it will become a WMA technology which then can result in over compaction if the contractor is not familiar with the procedure.
	2	High RA content mixes may contain some moisture of the RA (although below COLTO maximum of 0.5%) that can cause the mix to be tender.

The following paragraphs summaries the RA and WMA technology risks in each of the three phases.

- ***Design Phase:***

The main cause of risk in the design phase is that there are currently no specifications for the use of RA or WMA technology in the COLTO design manual which is the primary design manual that is used during road design in South Africa. There are over 20 different WMA technologies (of which each have different limits and advantages) available in South Africa which makes the risk of designing a WMA mix without standard specifications very difficult and risky. One of the main reasons for risk during the design phase of a high RA content mix (above 25%) is that designers do not include the variable properties of the RA's residual binder or aggregate sizes into their design parameters. A minimum RA content can thus only be specified after the RA's properties have been analysed as it is sometimes impossible to match the high specified RA content's properties with the mix designed for the project (example: to meet the specified grading of the mix or to achieve the desired binder content and viscosity through the blend of virgin binder and residual binder). Combining these reasons with a lack of experience and understanding of both these technologies can cause more risk to a project.

- ***Production Phase:***

The reasons for risks arising in the production phase of WMA is the lack of standard specifications for this technology which leads to WMA technology dosages being adjusted during the production phase which has an effect on the asphalt quality, cost and time of the project. The plant's capabilities are also one of the main reasons for the occurrence of risks in the production phase. WMA requires certain functions such as to maintain a constant temperature (which is much lower (up to 30°C) than the conventional temperature of the plant) to properly mix a WMA mix. RA also requires certain capabilities by the plant to produce a proper RA mix. These capabilities include: Managing the introduction of the RA into the mixing drum to avoid contact with the burner flame, to heat the RA to ensure the evaporation of most of its moisture. Quality control and monitoring of the RA stockpiles is another one of the reasons for risks arising in the production process. The stockpiles must be kept dry and the particle sizes must be monitored. The residual binder content in the RA as well as the residual binder's properties must be monitored throughout the production process as these factors have a direct effect on the quality of the final asphalt mix.

- ***Construction Phase:***

The construction phase was identified as the phase that holds the least amount of risk for a project that uses RA and WMA technologies. The only risk that was identified was caused by one of the benefits of WMA technology. Over compaction of the asphalt layer may occur as a result of the larger compaction window. This can however be easily eradicated by carefully monitoring the layer density during the compaction process.

In summary it can be said that the insufficient training and work experience along with a lack of specification and a lack of guidelines for the use of RA and WMA technologies are the main reasons for the risks on these technologies.

7.2.3 Other Findings Made

The current use of these technologies in the South African asphalt industry is limited. However the RA technology is considered by the specialists to be used more than the WMA technology. It was found that RA is used in most asphalt projects up to a RA content of 10%. However these low RA percentages are not always declared as RA. Most of the specialists that were interviewed only knew of two WMA projects currently on going (with at least 3 projects that are going to start soon). RA is driven by Sanral who is the largest road authority in South Africa. This technology will thus be introduced into more projects. The use of WMA technology also shows good signs for growth as the asphalt suppliers are introducing this technology permanently to some of their plants. Much Asphalt and National Asphalt (the two largest asphalt producers in South Africa) are committing plants to the permanent production of WMA mixes. The combined use of these technologies can potentially improve the benefits to the asphalt industry. This can also increase the use of WMA technology as the realisation of the combined benefit with RA technology may increase the specification of this (WMA) technology.

The future growth of these technologies was also investigated. Through the specialist interviews factors were identified that has an impact on the growth rate of these technologies. The factors that influence the growth of the RA technology are shown in Table 57.

	Table 57: Factors that influence the growth of RA technology	**Effect on the Growth**
1	Increase in the realisation of the economic (reuse of old bitumen and aggregate) and environmental (recycling) benefits.	Positive
2	South Africa uses thin asphalt layers which limits the available amount of RA. The use of RA can thus increase but will even out as the RA limit is reached.	Negative
3	The use of RA will increase fast as it is driven by asphalt suppliers. Asphalt suppliers realises the economic benefits of this technology and is thus interested in increasing RA use.	Positive
4	The use of RA will increase as it has the support from large road authorities (Sanral and eThekwini Municipality) and the idea of RA has been planted in South Africa for more than 20 years.	Positive

Table 57 also shows the effect these factors will have on the growth rate of RA technology. Factors 1, 3 and 4 will increase the growth rate. Factor 2 will slow the growth of the technology as soon as all the available RA is utilised. The RA technology will increase until the RA reaches its full utilisation capacity.

Table 58 shows the factors that were identified through the interviews that will affect the growth of the WMA technology.

	Table 58: Factors that influence the growth of RA technology	**Effect on the Growth**
1	Increase in the realisation of the economic and especially the environmental benefits.	Positive
2	As soon as WMA's performance properties can thoroughly be proven and recorded to be the same as HMA it can replace HMA in project specifications and increase the use of the technology.	Negative
3	Any HMA can be manufactured as a WMA. The technology is thus not limited to specific mixes.	Positive
4	Global pressure of technology development and green engineering can provide motivation for an increase use.	Positive
5	The increase in carbon taxes provides a financial incentive for asphalt manufacturers to invest in this technology.	Positive
6	The growth may be slow as the technology is fairly new to South Africa and the necessary knowledge to specify this technology in projects is lacking from many engineers and clients.	Negative

The growth of this technology will increase as factors 1, 3, 4 and 5 cannot be ignored. This growth will however be slow as factors 2 and 6 can take a while to be overcome. This technology is however not limited and can be used in any HMA mix. This technology thus has the potential to replace HMA completely.

The following road authorities were identified by the specialists as the authorities that are currently showing support to the use of these technologies:

- Kwazulu-Natal Department of Transport (Provincial),
- Gauteng Department of Roads and Transport (Provincial),
- eThekwini Municipality (Municipal),
- Sanral (National).

According to the data procured from the specialists the following provinces do not currently show interest in these technologies: Limpopo Province, Free State, Northern Cape, Eastern Cape and North West Province.

There are thus road authorities that are realising the benefits of these technologies. It is however of concern that five of the nine provinces in South Africa do not show interest in these technologies from a lack of knowledge and professional resources. It is thus important that Sanral starts to endorse these technologies as they are a country wide authority and serve as the client in major projects around the country (including the 5 non-interested provinces). These are however only a small number of authorities and the technology integration process can be considered as slow.

The current use of these technologies in South Africa is limited and is not specified in many projects at this stage. There is however factors that indicate that these technologies are growing in this industry. It is of concern how limited the authorities are that promote these technologies. This lack of interest by the authorities and other relevant entities can again be attributed to a lack of knowledge of these technologies. These authorities and entities that are aware of these technologies are sceptical of the insufficient proof of the performance capabilities of the new technologies (in comparison to conventional HMA).

7.3 Conclusion

This Chapter summarised the conclusions made of the benefit analysis and the risk analysis. The current use, future use and provincial interest of RA and WMA technology was also discussed to provide further insight. This chapter provides the basis to conclude the final findings made in this study as well as the recommendations that can be made for future research. Chapter 8 is the final chapter in this study and provides the findings made in this study as well as recommendation for future research.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

This chapter concludes this study. The aims of Chapter 8 are:

- To provide an overview of the topic and the objectives of this study,
- To provide the conclusions and findings that were made in this study,
- To provide recommendations for future research.

8.2 Thesis Overview

The problem statement of this study is:

This study investigates the benefits and risks of the integration and application of Warm Mix Asphalt (WMA) technology and Reclaimed Asphalt (RA) into the Hot Mix Asphalt (HMA) industry in South Africa.

The primary objectives that was set for this study is listed below:

- To motivate the use of WMA and RA technologies as a suitable technology for this study.
- To investigate what elements (health, environmental impact, quality and cost impact) of HMA will be affected by using new asphalt technology (WMA and RA technologies).
- To select an appropriate experimental strategy (case study, environmental and cost analysis) to determine the effect of these technologies as well as to determine the magnitude of the effect on HMA elements (environment and cost).
- To identify the benefits and risks that these technologies cause on HMA and the South African asphalt industry.
- To provide South African literature for further studies in this direction.

8.3 Conclusions

The research has led to a number of conclusions and findings regarding the use of RA and WMA technology.

The literature review concluded the following:

a) Procurement, production, construction, service life and end of life were identified as the five life cycle phases of HMA.

b) Four of the five phases were identified as being benefited by the RA and WMA technologies. They are the procurement, production, construction and end of life phases. RA technology was found to have a beneficial effect on the procurement and the end of life phases and WMA technology was found to have a beneficial effect on the production and construction phases.
c) Environmental impact reduction and cost savings were identified as the primary benefit areas of these technologies.
d) Life cycle assessment (LCA) and life cycle cost assessment (LCCA) were identified as the ideal tools to determine the magnitude of the impact of these technologies.
e) RA and WMA technology was identified as technologies that can have a potential beneficial impact on the South African asphalt industry.

The specialist interviews concluded the following regarding the use of these technologies in South Africa:

a) RA and WMA technology is not used extensively in South Africa at the moment and WMA technology is used less extensively than the RA technology.
b) The two largest producers of asphalt have committed monetary resources as well as some of their plant to the permanent production of WMA mixes which shows that they believe there is going to be an increase in the use of these technologies.
c) Factors have been identified that influences the growth of these technologies in South Africa (see Table 58 and 59). RA technology was found to show the most growth but that it will only grow until the RA utilisation capacity is reached (this is a low capacity as South Africa traditionally uses thin layered asphalt). WMA technology might grow at a slower rate but does not have any limitations as any HMA mix can be made a WMA mix.
d) There are a very limited number of authorities that are currently supporting these technologies. Four authorities were identified of which two are provincial, one is municipal and one is a national authority. This is worrying as the benefits of a technology can be large but if it is not implemented or specified it is of no use.
e) Sanral which is the largest road authority in South Africa was found to be the driving force behind the integration of these technologies and are currently specifying projects that implement these technologies. They also encourage further use and development of these technologies.
f) The lack of interest in some regions can be contributed to the diminishing of professional resources (engineers and specialists in the field of these technologies) in these regions and thus not being capable of constructive though and policy formulation in respect to these technologies

The specialist interviews concluded the following regarding risk identification of these technologies:

a) Risks were identified in the design, production and construction phases of the asphalt's life cycle. These risks are listed and described in Table 56 and Table 57.
b) The phases that hold the most risk for the integration of these technologies are the design phase and construction phase. The construction phase does not hold much risk.
c) The primary causes of the design risks are that the use of RA and WMA technology is not included in the standard design manuals. There are thus no standard guidelines for the use of these technologies and specifications must thus be drawn up for every project. There are a large number of WMA technologies available in South Africa to choose from which each has its own benefits for certain conditions. This makes it risky to design a mix without standard guidelines. The specification of minimum RA contents is also identified as a cause of risk as the RA must first be analysed to determine what the possible RA content is. Combining these reasons with a lack of experience and understanding of both these technologies can cause more risk to a project.
d) The primary causes of risk in the production phase include the fact that there are no specifications for the use of these technologies. This leads to the adjustment of technology (RA and WMA) dosages during the production phase (basically redesign) which leads to cost, time and quality risks. The use of these technologies requires certain plant capabilities. Quality risks can arise if these capabilities are not met. Procurement risks also arise as there are a limited number of plants with these capabilities in South Africa. Quality control is also a primary cause of risk in this phase. The RA stockpiles and the mix properties must be monitored throughout production (quality, cost and time risks caused).
e) The primary causes of risks in the integration of these technologies in South Africa are:
    - Lack of standard specifications,
    - Lack of knowledge and experience in the use of these technologies,
    - Lack of plants with the necessary capabilities,
    - Lack of proper quality control and monitoring measures.

The LCA and LCCA concluded the following about the benefits of these technologies:

a) Both the RA and the WMA technology induces a environmental impact reduction and a cost saving. This is proven by three sources, namely: Literature review, specialist interviews and the LCA and LCCA.
b) The combined use of these technologies induces an even more beneficial environmental and cost impact. This is also proven by three sources, namely: Literature review, specialist interviews and the LCA and LCCA.

c) RA reduces the cost and environmental impact of the procurement and the transportation phases. WMA technology reduces the environmental and cost impact of the production and the construction phases. This correlates with the findings made in the literature review.
d) The WMA technology has a larger environmental benefit as RA technology and RA technology has a larger cost benefit that WMA technology.
e) The magnitude of the energy and cost savings is 8.73% and 12.19% respectively for the case study project. The magnitude of the impact of these technologies is thus significant. Sensitivity analyses also showed that varying conditions still shows that the technologies are beneficial.

From these findings it can be concluded that the objectives of this study is achieved and that the use of these technologies has definite environmental and cost benefits and that the magnitude of these benefits are high enough not to be ignored. The current use of these technologies is however a cause for concern as there are only a few projects that implement them and only a few road authorities has warmed up to the use of these technologies. There is however indicators that show that there is an increase in the use of these technology. This growth is very gradual. The risks involved in using these technologies are caused by a lack of experience and knowledge of these technologies which is aggravated as there are no standard specifications for their use. These are thus risks that can be overcome by continuing the research in this field. These are technologies that can preserve our natural resources and also reduce cost of asphalt construction. It is however important that the right strategy must be put in place to integrate these technologies into the South African asphalt industry in such a way that minimal risk and monetary losses are achieved.

8.4 Recommendations

The following recommendations are made:

a) Workshops should be held to inform practitioners in the asphalt industry (engineers, suppliers, contractors and clients) of the benefit of using these technologies and the role each of them have to play to integrate these technologies in South Africa.
b) The use of these technologies to a smaller extent must be encourages. For example applying a RA of 20% rather than 40%. This reduces the risk of the use of these technologies and can help to gradually integrate the technology into the industry.
c) Consulting engineers must collaborate more with asphalt suppliers as these are the two groups that do the most research and testing in the RA and WMA technology field.
d) Standard specifications for the design of RA and WMA mixes must be constructed as well as proper quality control and monitoring specifications during the production of asphalt.

e) To conduct more LCA and LCCA on South African projects that uses these technologies to create a data base of the impact of these technologies on projects in South Africa. This data base can also be useful when different technologies and mix specifications are used as it can give the client insight to the benefit of these technologies. These analyses can also act as a tool to help with decision making regarding the appropriate mixes for certain conditions.

f) To set short and long term goals for different areas of the technology integration for example: To set a short term goal to inform an authority in each province of these technologies and then a long term goal to have a project in each province that implements these technologies.

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APPENDIX A: BITUMEN CLASSIFICATION TESTS

Penetration test:

A needle is used with specific dimensions. The needle is pressed into a sample of bitumen that must be prepared in the correct manner to avoid inaccurate results. The needle and the apparatus must be maintained and kept in a perfect working condition to ensure the accuracy of the test. The depth of penetration is measured in decimillimeter (This is a tenth of a millimetre). The average of three penetration measurements are calculated and rounded to the nearest whole unit. There are certain standards that need to be upheld. The load must be 100 grams, the temperature must be 25 degrees Celsius and the loading period must be 5 seconds. If the correct method is implemented, accurate results will prevail (Read & Whiteoak, 2003). Figure 27 shows a graphical illustration penetration test.

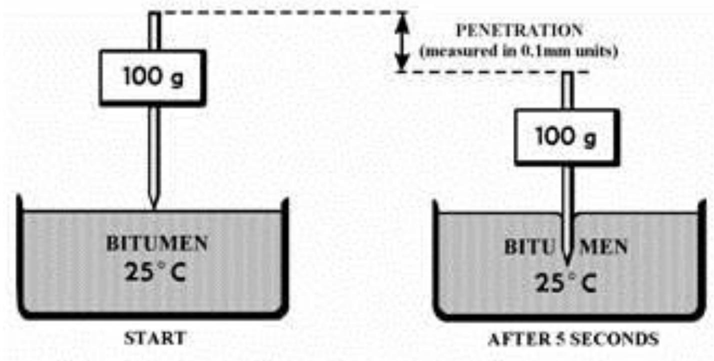


Figure 27: Penetration Test

(Highways Research Group, 2009)

Softening point test:

This test is also called the ring and ball test. This test determines at which temperature bitumen reaches a certain degree of softness. Bitumen does not have a specific temperature at which it becomes fluid. The softening point is thus an arbitrary temperature.

Melted bitumen is poured into a brass ring. When it cools down a steel ball (3.5 grams) is placed on the bitumen sample. The temperature is now increased by 5 degrees Celsius every minute. The ball along with the bitumen lowers through the ring as the temperature increases. When the ball reaches a base plate 25mm below the ring, the temperature is recorded. From these temperatures the softening point is determined. The apparatus is shown in Figure 28 (Read & Whiteoak, 2003).

Figure 28: Softening Point Test

(Ammann-Group, 2011)

APPENDIX B: HOT MIX ASPHALT (HMA) GRADATIONS

The grading envelope that is indicated in the graphs indicates the boundaries of the specific gradation. These envelopes are available in the Standard Specifications of Road and Bridge Works of State Road Authorities provided by the Committee of Land Transport Officials (COLTO) (Committee of Land Transport Officials (COLTO), 1998). When designing a mix the gradation must fit the envelope as prescribed by the engineer or client.

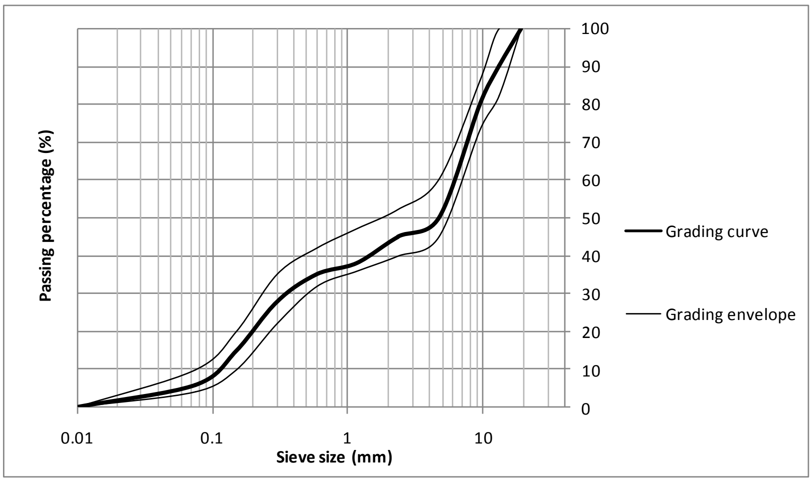


Figure 29: Semi-gap-graded (19mm)

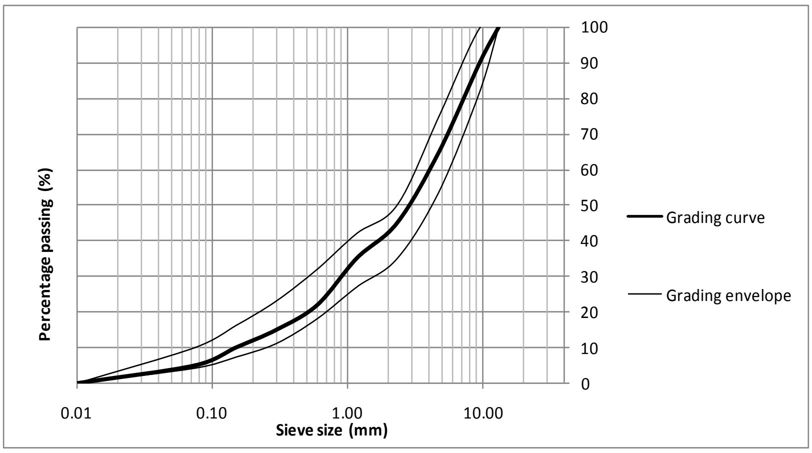


Figure 30: Continuously-graded (medium 13.2mm)

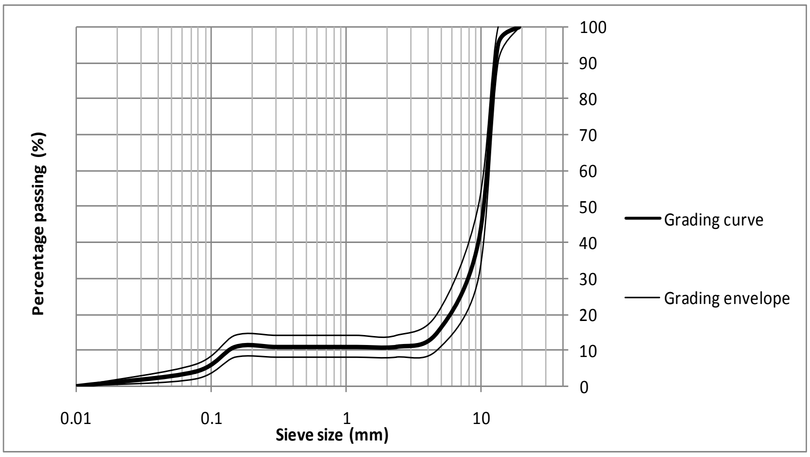


Figure 31: Open-graded (13.2mm max)

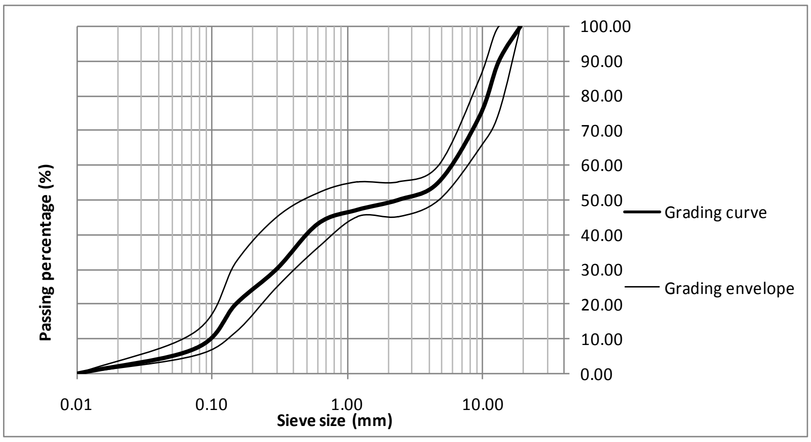


Figure 32: Gap-graded (high-stone-content)

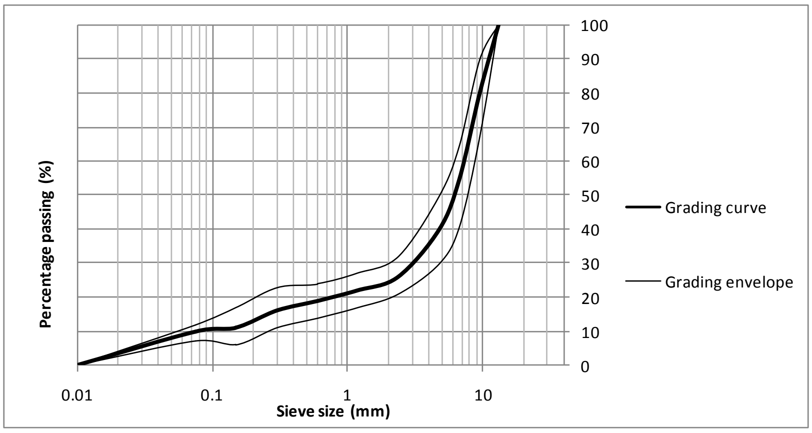


Figure 33:SMA (13.2mm max)

APPENDIX C: DRUM AND BATCH PLANTS

C-1: Drum Plants

A typical drum plant is illustrated in Figure 34 (European Asphalt Pavement Association (EAPA), 2011) as well as a description of the different components:

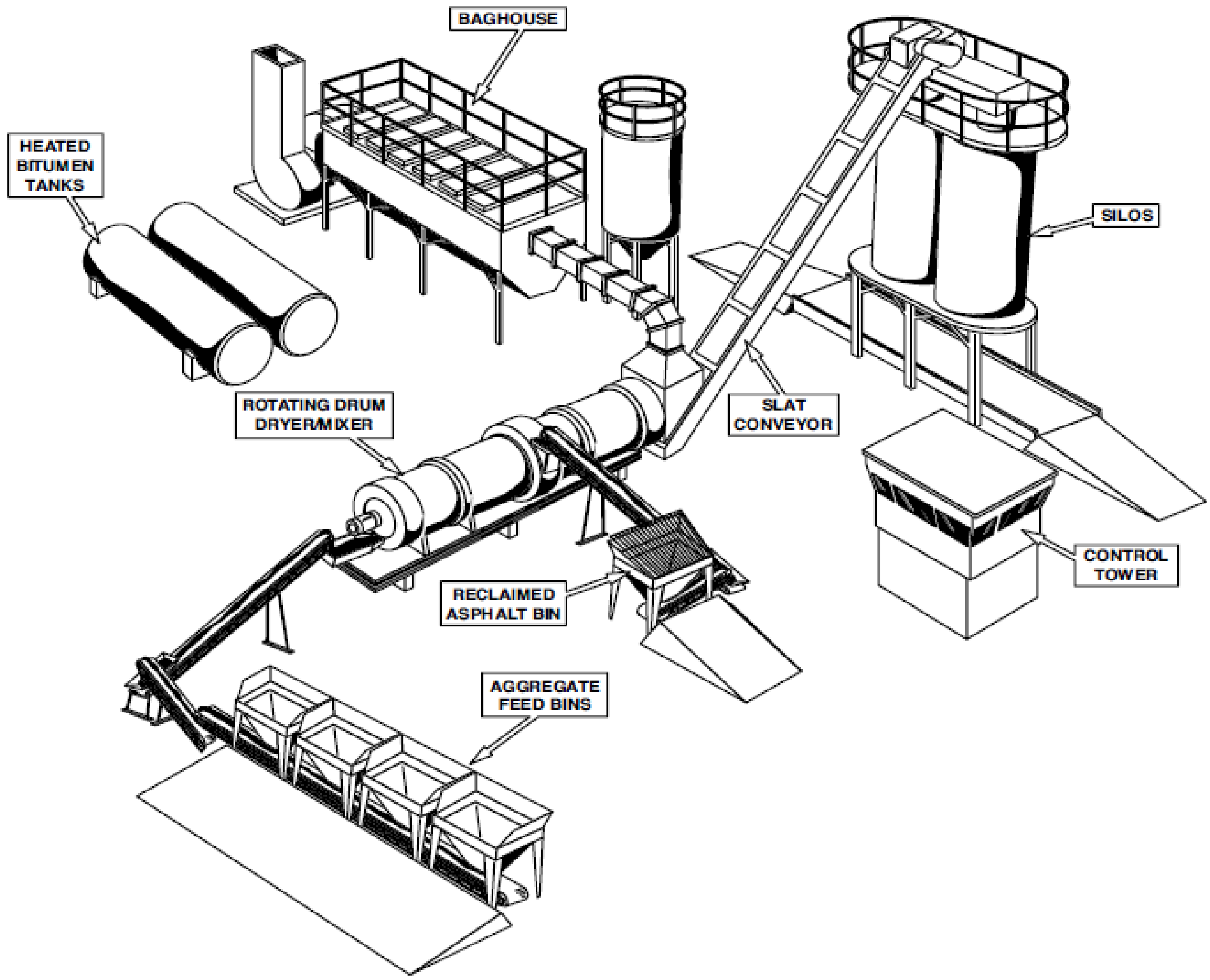


Figure 34: Drum Plant Layout

1. Aggregate feed bins:

These bins are filled with the mineral aggregate by a loader that collects the aggregate from the stockpiles after it has been crushed. These feed bins accurately measure the amount of different sizes of aggregate required as specified by the mix design (gradation). These aggregates are then transported by the conveyor into the mixing drum (Green, 2006).

2. Reclaimed Asphalt (RA) bin:

The RA bin feeds the RA into the mixing drum by using the centre entry method. RA consists of old asphalt material that causes large amounts of blue smoke when it comes into direct contact with the burner flame. It can also render the RA unusable. The RA is thus added into the middle of the mixing drum which allows the dried aggregate to come between the flame and the RA. The RA is thus heated through conduction (S & Mallick, 1997).

3. Rotating drum dryer/mixer:

This drum dries and heats the aggregate before mixing it with the bitumen as well as in some cases the RA. This drum has a burner flame that provides the heat. The drum rotates and has spiral flights inside that direct the material through the drum. The drums can be configured into two variations namely counter-flow drum and a parallel flow drum. In a parallel flow drum the flame and the material moves in the same direction (the aggregate thus enters the drum on the flame's side). In the counter-flow drum the flame blows into the opposite direction in which the aggregate moves. The asphalt is mixed in this drum at a temperature of between 150°C and 190°C (Indiana Department of Transportation, 2012).

4. Heated bitumen tanks:

These tanks keep the bitumen at a temperature of between 150°C and 180°C. The bitumen is then pumped into the mixing drum. The bitumen must be maintained at these temperatures otherwise it could lead to blocked pipes and massive time delays (Indiana Department of Transportation, 2012).

5. Baghouse:

The baghouse is a modern component of asphalt plants. It is designed to reduce the amount of fines released into the air by the mixing drum. The baghouse consists of a large amount of bags (up to 800). A large fan sucks in the dirty air and sucks it through the fabric bags that catch the fines in the dirty air. The baghouse releases clean air into the atmosphere and stockpiles the fines at the bottom of the baghouse which can be reused as raw aggregate.

An alternative to baghouses are wet scrubbers. A wet scrubber reduces air emissions of the plant exhaust gasses by catching the dust in the emissions with water droplets. However the material that is removed by the wet scrubber cannot be reused. The baghouse is thus the favourable option (Indiana Department of Transportation, 2012).

6. Silos

After the asphalt is mixed a conveyor transports it up into the silos where it is kept until it is taken out to the paving site by trucks.

C-2: Batch Plants

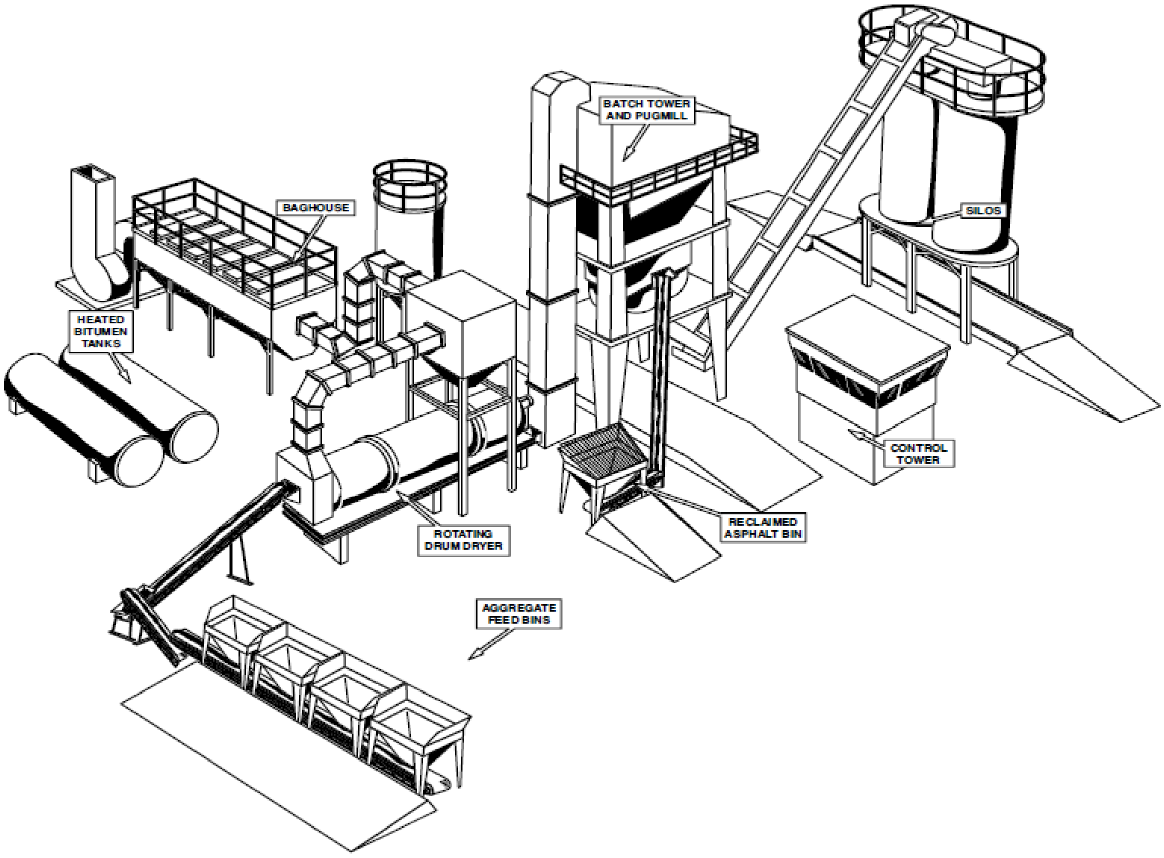


Figure 35: Batch Plant Layout

The batch plant illustrated in figure 35 (Indiana Department of Transportation, 2012) fulfils the same purpose as a drum plant. There are similarities in the components of the two types of plants that include the aggregate feeding bins, the RA bins, the heated bitumen tanks, the storage silo's as well as the dust removal components.

The main difference between a batch plant and a drum plant occurs when the aggregate is mixed with the bitumen. When the heated aggregate exits the drum it is elevated to the batch tower where the aggregate is divided into batches and then mixed with the RA and the bitumen.

APPENDIX D: SUPPLIERS' ASPHALT CONTRIBUTION

From: Sean Pretorius

Sent: 02 October 2013 12:59 PM

To: Riaan Stander

Subject: Suppliers' asphalt contribution

Hi Sean,

Can you please answer the following questions?

- **Are National Asphalt and Much Asphalt the two largest asphalt suppliers in South Africa?** *Yes.*
- **What is the market share of these two companies?** *Much Asphalt: 50% and National Asphalt: 30%. Estimated in September 2013.*

Sean Pretorius

Office: Bon Accord +27 86 146 6656

Email: sean@nationalasphalt.co.za

APPENDIX E: MIX MODEL CORESPONDENCE

E-1: Mix Temperature and Binder Savings

From: wynand@nationalasphalt.co.za
Sent: 01 October 2013 08:13 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: WMA additives

Hi Riaan,

Can you please verify or correct my statements?

- **With a 20% RA content the temperature increases to around 195°C which gives an energy increase of 10%.** [WN] *standard mixing temperature vary due to binder type the modified binders are generally mixed between 165°C and 175°C we normally do not increase the mixing temperature with the 20% RA it will all depend on the type of plant used. Our plants preheat the RA with the virgin aggregates the Double Barrel concept. If a standard plant is used centre feed ring the virgin aggregates are then what we called supper heated to ensure sufficient heat transfer to the RA. Then you might see the high temps you mentioned. The energy savings will also vary from plant to plant but you assumption could be used as an average.*
- **The bitumen savings on each project (that uses RA and WMA technology) vary as it is dependent on what WMA additive and RA content is used as well as what the required binder content is for the specific project**. *[WN] the bitumen savings is purely linked to the recovered bitumen from the RA and not as result of the additive. The additive any rejuvenate the bitumen. The rest of your statement is correct.*

Kind Regards,

Wynand Nortjè

Technical Manager

E-2: Binder Savings on the N1 Project

From: Chris Stander
Sent: 01 October 2013 09:15 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: Binder Savings on the N1 Project

Hi Riaan,

The following statements are correct.

- ***1.8% of the binder content (N1 project binder content specification is 4%) is made up of the residual bitumen obtained from the RA (when 40% RA is used), which is thus a bitumen saving of 45%.***
- ***The Sasowax 1655 was initially applied at 0.7% of the virgin bitumen volume.***

Regards,

Chris Stander

Director

APPENDIX F: ENVIRONMENTAL ANALYSIS'S SITE CORRESPONDENCE

Background:

Appendix E provides the site correspondence and data gathering that is used in Chapter 4: Environmental Analysis. These are mainly e-mails that were used during the study to communicate to the asphalt supplier, National Asphalt, which provided the asphalt for the N1 project.

F-1: Reclaimed Asphalt (RA)

From: Chris Stander
Sent: 04 March 2013 09:15 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: Reclaimed Asphalt (RA)

Hi Riaan,

See below:

I would like to know the following if possible:

- **What are the main components and events that are energy consuming during the procurement of RA?** *Milling of RA, crushed by impact crusher, screened by screening plant and an additional loader is required*.
- **What type of milling machine are you using to take out the RA (I want to find out its diesel consumption)?** *Wirtgen W2000*
- **What is type of impact crusher is used? Fuel consumption and capacity?** *Terex Impact crusher. 150 t/hour. Consumption +/- 34 l/hour.*
- **What type of screening plant is used? Fuel consumption and capacity?** *Terex Finlay 683. 150 t/hour. Consumption +/- 15 l/hour.*
- **What type of loader is used? Fuel consumption?** *CAT 928. Consumption +/- 15 l/hour.*
- **What is the average density of the RA that is taken out on the N1 project?** *+/- 2500 kg/m3*

Regards,

Chris Stander

Director

F-2: WMA Additives

From: wynand@nationalasphalt.co.za
Sent: 05 March 2013 08:13 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: WMA additives

Morning Riaan,

See below:

I would like to find out what type of WMA technologies you are using at the moment?

- **Product name*[WN]*** *- we use a few, Foam, Sasobit, Sasoflex, en EcoNat. There is another one that we are accredited by the WMAIG – Rediset is also on the list.*
- **Where does it get added to the mix*[WN]*** *- Foam gets added in the production line, the rest of them gets mixed into the bitumen in the mixing tanks*.
- **With what ratio do they get added*[WN]*** - *Foam does not have a specific ratio but is based on the addition of water which is between 1 and 3% per bitumen volume, Sasobit's ratio is 1.5% of the bitumen volume, Sasoflex is a 2 in 1, its ratio is 4.2% of the bitumen volume, but is not only a WMA technology but also an A-E2 modifier, EcoNat's ratio is o.5% of the bitumen volume and the Rediset's ration 1.5%*.
- **Where does these products come from*[WN]*** - *foam is done with a foam generator which we imported, we have started with an in-house one but this is very basic, Sasobit and Sasoflex are produced locally by Sasol, Econat is produced locally by us and Rediset is imported from Sweden.*
- **What WMA technology is currently used on the N1 project *[WN]*** *– Sasowax 1655 that is produced locally by Sasol.*

TECHNOLOGY

- Foam Bitumen is a mixture of water and bitumen.
- It is typically 99% bitumen, 1% water.
- It is produced by injecting the cold water into the hot bitumen in a foaming chamber.
- The bitumen expands to about 15 times its original volume and forms a fine mist of foam, which is highly effective in wetting and coating of the aggregate particles, leaving a residual bitumen with similar properties to the original bitumen.
- The time that the expanded bitumen takes to settle to half its expanded volume is called the half-life. 60 seconds is generally a desirable value.

Kind regards,

Wynand Nortjè

Technical Manager

F-3: Transportation

From: Chris Stander
Sent: 13 March 2013 08:24 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: Transportation

Morning Riaan,

See below,

Here are the questions regarding transportation.

- **Please provide the locations where the following materials are procured, the distance from the plant to these places, the trucks that are used and their fuel consumption:**

  Aggregate: *Elandsrand (Carletonville) 76 km. 27 ton loads. Consumption 1.8 km/l.*

  Bitumen: *Sapref Durban. 567 km. 30 ton loads. Consumption 1.75 km/l.*

  Lime: *Lime Distributors. Vereeniging. 25 km. 33 ton loads. Consumption 1.75 km/l.*

  WMA additive (sasowax 1655*):* *Sasol Sasolburg.25 km. We use +/- 15 tons on the whole project and can thus transport it with a bakkie. Consumption 2.8km/l*

- **I also want to know what trucks they use to transport the RA?** *10 m3 (13 ton) 1.9 km/l.*
- **I also want to know what trucks they use to transport the asphalt from the plant to the paver?** *10 m3 (13 ton legal) 1.9 km/l.*
- **I also want to confirm the distance from the site to the plant, according to me it is as follows:**

The plant is next to the N1. The project starts 10km further down the N1 where the road crosses the Vaal River. The trucks must then drive another 10km to the Parys Bridge to turn and come back to the plant. The project ends at the toll gate (how far is the Parys Bridge from the toll gate?) *This is right; the Parys Bridge is 1km from the toll gate.*

Chris Stander

Director

F-4: Asphalt Laying and Compaction

From: Chris Stander
Sent: 18 March 2013 10:53 AM
To: Hardus Van Aswegen
Cc: Riaan Stander
Subject: FW: Asphalt Laying and Compaction

- **Paving process: During paving the only energy usage is caused by the paver? What pavers do you use and what is their diesel consumption? Is there any other machines used during paving?**

  Paver used is a Voegele 1800-2. Gas usage = 48 kg/day.

- **Compaction process: For a conventional HMA without RA and WMA technologies. What types of rollers are used? How many repetitions are required to meet compaction specifications? As well as their fuel consumption?**

  2 ton steel wheeled roller: Does 2 passes vibrating and 2 passes not vibrating. Consumption 3l/hour.

  Pneumatic rollers (X 2): Does 4 passes. Consumption 8 l/hour per roller.

  Three point roller: If needed does 3 passes. 7 l/hour.

Regards,

Chris Stander

Director

F-5: Sensitivity Analysis

From: Chris Stander
Sent: 13 September 2013 04:16 PM
To: Riaan Stander
Subject: Sensitivity Analysis

See my reply hereunder.

I have identified the most influential factors in my Life Cycle Assessment (LCA) that I need to do a sensitivity analysis on. As I only have the values for these factors for the N1 project, I would like to investigate the effect variable values will have on my LCA. Can you answer the following questions regarding varying values:

Can you provide me with contact details of other asphalt suppliers that can share their values with me? If it is not possible because of confidentiality principles, can you please answer the questions yourself and explain why this confidentiality is so important. *The other major supplier of asphalt in*

South Africa is Much Asphalt with approximately a 50% market share. Their contact details can be found on their website.

Please state the number of plants that you are managing? *We have 16 asphalt plants spread across KZN, Northern Cape, Gauteng and Mpumalanga. I personally manage 6 of them. We currently provide 30% of the market share.*

Can you please provide the range that you think covers the HFO usage according to your experience? Thus the least efficient to most inefficient. (example: 4 l/ton – 12 l/ton) *In our case, this varies from 5.5 to 10 l/ton. The type of mix, and especially the moisture content of the aggregates have a huge influence on the HFO consumption.*

Can you please provide the range in which aggregate prices vary? *Again, in our case it varies from R 140 to R 325 per ton delivered.*

Can you please provide me with the bitumen listed prices if possible? *See attached.*

Regards,

Chris Stander

Director

APPENDIX G: COST ANALYSIS SITE CORRESPONDENCE

G-1: Life Cycle Cost Analysis

From: Chris Stander
Sent: 02 April 2013 10:08 AM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: Life Cycle Cost Analysis

Hi Riaan,

See below the answers to your questions.

I am currently busy with the cost analysis of the project (excluding the plant modification costs). Can you please help me with the following questions?

- **At what price do you purchase aggregate, bitumen, WMA additive (Sasowax) and lime?**
  We buy aggregate form Stone & Allied close to Carletonville @ R140/ton (R75/ton for aggregate + R65/ton for transport), thus includes transport. Bitumen is bought from Shell in Durban. The listed price for bitumen is R6 400/ton + R610-35 for transport. The Sasowax is bought from Sasol at a price of R23 528-69/ton. The lime is delivered by Lime Distributors for R1 871-21/ton.
- **What energy sources are used during the asphalt production? How much?**
  LBF (instead of diesel), HFO, electricity, natural gas (if available). LBF: 7500 litres/month (dependent on the amount of running hours), HFO: 8 litres/ton (on average).
- **At what price do you buy LBF and HFO for the plant?**
  LBF is bought from Twin Hydro (Sasolburg) for R8-82/litre delivered. HFO is bought from FFS for R5-45/litre delivered.

Regards,

Chris Stander

Director

G-2: Vanderbijlpark Plant Electricity Bill

Eskom

ESKOM HOLDINGS SOC LIMITED REG NO 2002/015527/06
VAT REG NO 4740101508

CENTRAL REGION
PO BOX 8810 JHB 2000

CONTACT CENTRE:	(0860) 037566
FAX NO:	(0866) 979065
E-MAIL:	CENTRAL@ESKOM.CO.ZA
WEB:	WWW.ESKOM.CO.ZA

Eskom

TEL:	08600 37566
SMS:	082 941 3707
	083 647 1951
	084 655 5778

CUSTOMER SELF SERVICE WEBSITE:
https://csonline.eskom.co.za

CENTRAL REGION
PO BOX 8810 JHB 2000

NATIONAL ASPHALT
PO BOX 1657
HILLCREST
3650

YOUR ACCOUNT NO	6052209165
SECURITY HELD	67270.00
BILLING DATE	2013-03-28
TAX INVOICE NO	605229169705
ACCOUNT MONTH	MARCH 2013
CURRENT DUE DATE	2013-04-12
VAT REG NO	4160181709

DIRECT DEPOSIT DETAIL	
BANK:	First National Bank
BRANCH CODE:	255005
BANK ACC NO:	62006191077

TAX INVOICE

E-MAIL: Freda@nationalasphalt.co.za

ACCOUNT TRANSACTION SUMMARY

ADMINISTRATION CHARGE		R	315.28
DIST. NETWORK ACCESS CHARGE		R	5,115.60
ENERGY CHARGE (STD)	13,427.00	R	8,269.07
ENERGY CHARGE (PEAK)	4,825.00	R	3,387.63
ENERGY CHARGE (OFF)	6,838.00	R	1,773.94
ELECTRIFICATION AND RURAL SUBS (ALL)		R	1,146.52
ENVIRONMENTAL LEVY		R	878.08
SERVICE CHARGE		R	1,124.76
TOTAL CHARGES FOR BILLING PERIOD		R	20,010.88

ACCOUNT SUMMARY FOR MARCH 2013

BALANCE BROUGHT FORWARD	(Due Date 2013-03-14)	R	13,094.83
PAYMENT(S) RECEIVED	Direct Deposit - 2013-03-07	R	-13,094.83
TOTAL CHARGES FOR BILLING PERIOD		R	20,010.88
VAT RAISED ON ITEMS AT 14%		R	2,801.53

COPY ONLY

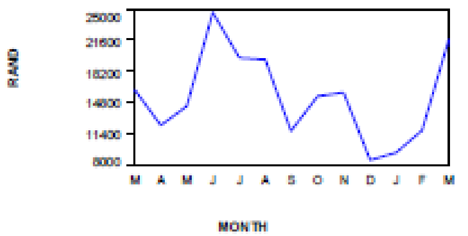
>>>>>>>> 9207 2605 2209 1652 0934
6052209165

ARREARS						
>90 DAYS	61-90 DAYS	31-60 DAYS	16-30 DAYS	CURRENT		
0.00	0.00	0.00	0.00	22,812.41	TOTAL DUE R	22,812.41

ACCOUNT NO / REFERENCE NO
6052209165
NAME
NATIONAL ASPHALT
FAX NUMBER
0865319171

TOTAL AMOUNT DUE

22,812.40



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PAYMENT ARRANGEMENT
INSTALMENT
0.00
ARREARS
0.00
DUE DATE
2013-04-12
AMOUNT PAID

LATE PAYMENT CHARGES WILL BE ADDED TO OVERDUE ACCOUNT

Figure 36: Vanderbijlpark Plant Electricity Bill 1

Eskom

CENTRAL REGION
PO BOX 8810 JHB 2000

CONTACT CENTRE:	(0860) 037566
FAX NO:	(0866) 979065
E-MAIL:	CENTRAL@ESKOM.CO.ZA
WEB:	WWW.ESKOM.CO.ZA

NATIONAL ASPHALT
PO BOX 1657
HILLCREST
3650

YOUR ACCOUNT NO	6052209165
BILLING DATE	2013-03-28
TAX INVOICE NO	605229169705
ACCOUNT MONTH	MARCH 2013
CURRENT DUE DATE	2013-04-12
VAT REG NO	4160181709
NOTIFIED MAX DEMAND	315.00
UTILISED CAPACITY	315.00

CONSUMPTION DETAILS (2013-02-25 - 2013-03-24)

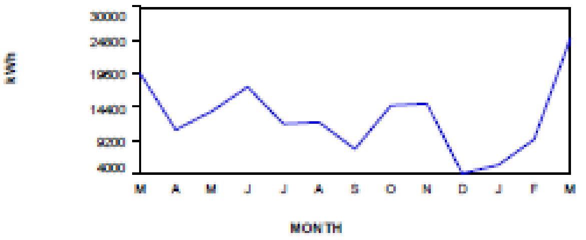
ENERGY CONSUMPTION OFF PEAK kWH	6,835.53
ENERGY CONSUMPTION STD kWh	13,427.39
ENERGY CONSUMPTION PEAK kWh	4,824.84
ENERGY CONSUMPTION ALL kWh	25,087.76
DEMAND READING - KW/KVA	259.11
REACTIVE ENERGY - OFF PEAK	3,858.65
REACTIVE ENERGY - STD	10,253.56
REACTIVE ENERGY - PEAK	3,556.70
REACTIVE ENERGY - ALL	17,668.91
LOAD FACTOR	18.00

PREMISE ID NUMBER 6052209263 TARIFF NAME: Miniflex Interval

PLOT 10 RIETSPRUIT

Administration Charge @ R11.26 per day for 28 days	R	315.28
Network Access Charge 315.00 kVA @ R16.24 : = R16.24/kVA	R	5,115.60
Low Season Standard Energy Charge 13,427 kWh @ R0.4669 /kWh	R	6,269.07
Low Season Peak Energy Charge 4,825 kWh @ R0.7021 /kWh	R	3,387.63
Low Season Off Peak Energy Charge 6,836 kWh @ R0.2595 /kWh	R	1,773.94
Electrification and Rural Subsidy 25,088 kWh @ R0.0457 /kWh	R	1,146.52
Retail Environmental levy charge 25,088 kWh @ R0.035 /kWh	R	878.08
SERVICE CHARGE	R	1,124.78
TOTAL CHARGES	R	**20,010.88**

COPY ONLY



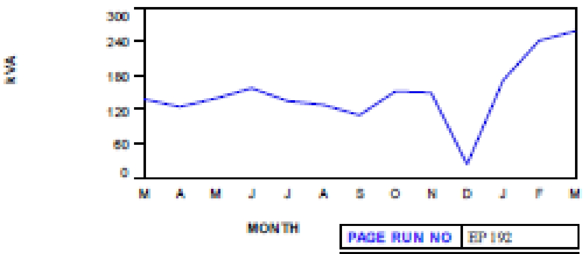


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Figure 37: Vanderbijlpark Plant Electricity Bill 2

G-3: Additional Cost of RA

From: Riaan Stander [mailto:15430103@sun.ac.za]
Sent: 03 April 2013 10:07 AM
To: Chris Stander
Subject: Additional Cost of RA

Hi Riaan,

See the answers to your questions below.

- What are the main modifications and extras that need to be used to be able to use RA?

An impact crusher, a screening plant and a loader is required. The plant must also be modified to be able to process RA.

- **What are the prices of these modifications if possible?**

The impact crusher's quotation is attached (VAT included), screening plant's quotation is attached (VAT included), the loader (CAT 928H) prices at R1.5m with VAT included.
A new asphalt plant that can process RA costs R11, 5 million. This is the price of a completely new plant. The Vanderbijlpark plant was upgraded to a RA plant. This modification cost R7 million. At this plant the old cold feed bins and the old hot storage. The heating and mixing drum, wet scrubber and RA bins are new. Both the new plants as well as the plant upgrades are done by Comar.

Regards,

Chris Stander

Director

G-4: Impact Crusher Quotation

PILOT CRUSHTEC

PILOT CRUSHTEC (SA) (PTY) LTD

CO. REG. NO.: 2005/002689/07

VAT REG. NO. : 4560218465

PO BOX 30032
JET PARK, 1469
SOUTH AFRICA

Email : accounts@pilotcrushtec.com
Tel: +27 (011) 842-5600
Fax: +27 (011) 842-5620

STATEMENT

TÜVRheinland® CERT ISO 9001

NATIONAL ASPHALT (PTY) LTD

PO BOX 247
PRETORIA 0009

Date:	31/03/2013
Account Number:	NAT001
Page No:	1

PLEASE NOTE THAT OUR COMPANY NAME, VAT NUMBER AND BANKING DETAILS WILL CHANGE WITH EFFECT FROM 1 APRIL 2013. A SEPARATE NOTIFICTION WILL FOLLOW SHORTLY.

Date	Document No.	Description	Invoices	Payments/Credits	Balance
26/03/2013	IN300374	Tax Invoice-SEAN PRETORIUS	R 3,385,800.00		R 3,385,800.00
26/03/2013	CN300020	Applied: IN300374		R 3,385,800.00	R 0.00
29/03/2013	IN300399	Tax Invoice-NAO48413	R 3,385,800.00		R 3,385,800.00

PAYMENT TERMS ARE NETT AND STRICTLY 30 DAYS FROM DATE OF STATEMENT

91 and Over	61 - 90 Days	31 - 60 Days	Current	Total Due:	R 3,385,800.00
R 0.00	R 0.00	R 0.00	R 3,385,800.00		

Figure 38: Impact Crusher Quotation

G-5: Screening Plant Quotation

PILOT CRUSHTEC

PO Box 30032, Jet Park, 1469, South Africa
26 Yaldwyn Road, jet Park, Boksburg, South Africa
Tel: +27 842 5600 Fax: +27 11 842 5610
www.pilotcrushtec.com

QUOTATION

TO:	NATIONAL ASPHALT
ATT:	NEELS SMITH
E-MAIL:	neels@nationalasphalt.co.za
FROM:	WIKUS KLEYHANS
DATE:	5 April 2013
NO. OF PAGES:	2
OUR REF:	LB/APR-13/05-02
SUBJECT:	**NEW SANDVIK QA140 MOBILE SCREEN**

Dear Neels,

We thank you for your enquiry and take pleasure in submitting our quotation for your consideration.

1.0 **SCOPE OF SUPPLY**

This offer is for the supply of **a New Sandvik QA140 Mobile Screen** as detailed below (technical specifications attached).

2.0 **PRICE**

DESCRIPTION	QTY	UNIT PRICE	TOTAL PRICE
New Sandvik QA140 Mobile Screen	1	R 1,730,000.00	R 1,730,000.00
		VAT@14%	R 242,200.00
		TOTAL	R 1,972,200.00

3.0 **PLANT COMMISSIONING**

A total number of 1 day will be allowed for commissioning, including travel time. Should the total number of days be exceeded due to circumstances beyond our control, then an additional amount of ZAR 6 000.00 will be charged, per technician for each day. Please note that we will require written confirmation that all the equipment has arrived on site at least 1 week prior to sending our technician.

Please note that should commissioning not be done by our qualified Pilot Crushtec (SA) (Pty) Ltd personnel, then NO WARRANTIES will be applied to the equipment.

innovative mobile crushing, screening and washing solutions

TÜVRheinland CERT ISO 9001

PILOT CRUSHTEC INTERNATIONAL (Pty) Ltd Reg. No: 2012/159891/07 Director: S Scherf (CEO)

Figure 39: Screening Plant Quotation

G-6: RA Statistics

From: Deon Pagel
Sent: 18 April 2013 03:26 PM
To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]
Subject: RA Statistics

Morning Riaan,

See below the answers to your questions:

I am currently busy with a cost analysis and as you are a member of Sabita you might be able to assist me in some problems.

- **What is the yearly amount (%) of asphalt mixes that uses RA of the total annual asphalt production? In 2005 there was a study done by Sabita that estimated that it was 5% of the annual production, I am sure that this value increased?**
- **What is the average amount (%) of RA that is currently mixed into asphalt mixes in South Africa?**

[DP]: *If you look back to the estimated 5% in 2005 it might have been high then. In 2008 the first big trials with more than 10% RA started (this was done with WMA in mind).This was followed in 2009 and 2010 by a third trial where 15 000 tons was laid. The highest RA content was 40% and it was produced at a temperature of 30°C below conventional HMA mixing temperature.*

The norm that is accepted as a standard where no savings is expected from the reuse of bitumen is 10%.These days it is not unusual to see a RA content of 20% and even 25% as it increases the benefits of the bitumen and aggregate savings which leads to less expensive asphalt.

There has also developed a tendency by SANRAL over the last few months to prescribe 40% RA in the base (BTB) mix. This is definitely the future and more contracts like this will come out.

To answer your first question the total RA mixes at the moment is probably around 10% of the annual asphalt production, but this will increase drastically within the future. It will not be long before it moves up to 15% or even 20%.

Regards and good luck,

Deon Pagel

G-7: Current NA Plants

From: Chris Stander

Sent: 29 July 2013 09:27 AM

To: Stander, AH, Mnr <15430103@sun.ac.za> [mailto:15430103@sun.ac.za]

Subject: Current NA plants

Hi Riaan,

What is the annual asphalt production of National Asphalt? *This will be close to 960 000 tonnes. (March 2013 to Feb 2014)*

How many plants do you have that can produce asphalt that contains RA? *Currently we have 4 plants that can do that.*

What yearly growth rate (as a percentage) can be used for national asphalt (asphalt production growth)? *I have got it as 5%. This will also depend on market conditions.*

What is the life expectancy of the plant modifications? They include: screening plant, impact crusher, extra loader as well as plant mods. I reckoned between 10-15 years? *This will obvious depend on production figures, but you can use it as such.*

Regards,

Chris Stander

Director

G-8: Bitumen Whole Sale Price

Bitumen Whole Sale List Price

Month	BP	Shell			Engen		
		40/50	60/70	80/100	40/50	60/70	80/100
		35/50	50/70	70/100	35/50	50/70	70/100
12 Sep 13		6,750	6,750	6,790	6,590	6,590	6,590
Sep-13		6,900	6,900	6,940	6,590	6,590	6,590
Aug-13		6,550	6,550	6,590	6,640	6,640	6,640
Jul-13		6,850	6,850	6,890	6,720	6,720	6,720
Jun-13		6,500	6,500	6,540	6,240	6,240	6,240
May-13		6,300	6,300	6,340	6,240	6,240	6,240

Bitumen Whole Sale List Price

Masana (BP)			Sasol			Tosas (SA)	Total (SA)			Sambit	Caltex
40/50	60/70	80/100	40/50	60/70	80/100						80/100
35/50	50/70	70/100	35/50	50/70	70/100		35/50	50/70	70/100		70/100
6,530	6,530	6,530	7,004	7,002	6,997	8,573	7,504	7,296	7,172		6,167
6,530	6,530	6,530	7,004	7,002	6,997	8,573	7,504	7,296	7,172		6,167
6,530	6,530	6,530	7,107	7,106	7,100	8,689	7,509	7,401	7,177		6,560
6,830	6,830	6,830	7,376	7,374	7,369	8,990	7,694	7,583	7,354		6,560
6,430	6,430	6,430	6,856	6,854	6,849	8,334					6,020
6,430	6,430	6,430	6,800	6,798	6,793	8,334	7,089	6,886	6,776		6,020

Figure 40: Bitumen Whole Sale Price